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PLASTICS AND THEIR APPLICATION IN THE ELECTROTECHNICAL INDUSTRY

by J. C. DERKSEN and M. STEL.

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Plastics is a name with which almost every one is familiar now that fancy goods and objects of domestic use are being made from these materials. Plastics were first used in the electro-technical industry more than 20 years ago but the rapid developments of recent years in this field have created all kinds of new possibilities. All plastics are essentially comprised of macro-molecules, each consisting of a very large number of atoms and formed from much simpler molecules by a repeated chemical binding process. There is a very wide choice of available basic materials, and so a great variety of plastics can be made with a surprising range of properties.

Since the beginning of the nineteenth century chemists have developed a number of new materials for industrial uses and for the community at large. From natural rubber has been derived, by chemical treatment with sulphur, what is now known as vulcanized rubber, this having better technical properties than natural rubber. Cellulose has been extracted from vegetable fibres and is converted with nitric acid into nitrocellulose, from which are derived celluloid (a substitute for ivory) and rayon (artificial silk). Casein has been used for making artificial horn.

During the last 20 years these developments have taken the world by storm: the artificial products industry has advanced by leaps and bounds. This industry however has reached a new stage of development, in that whereas formerly the aim was to imitate natural materials now many synthetic products are being produced which have exceptional properties not found in nature and which, therefore, can no longer be said to be artificial. "Philite" and "organic glass" are examples of such products, all of which have been given the name of "plastics". By this term is understood any material the main component of which is a macro-molecular substance, usually organic, and which in some stage of the processing is either plastic or liquid and solidifies in a later stage.

In almost every domain we come across articles made from plastic materials. These materials play

an important part also in the electrotechnical industry: the development of radio, television and radar, to mention only a few examples, would certainly have been impossible if no plastics had been available as raw materials.

The fact that the electrotechnical industry finds a great use for plastics is due in the first place to the valuable electrical properties which most of these materials are found to possess, such as high break-down strength, low dielectric losses and high "non-tracking" quality¹). Polystyrene and polyethylene for instance have very low dielectric losses, and moulding materials of urea-formaldehyde are highly proof against "tracking".

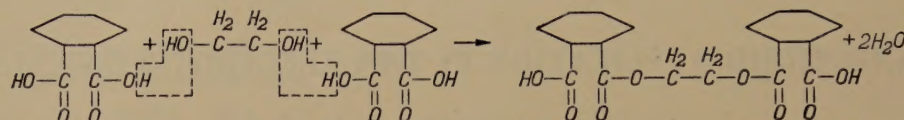
But these favourable electrical properties are not the only reasons, because other materials like porcelain and mica possess them too. The outstanding property which makes plastics so attractive, and by reason of which they excel over the other materials just mentioned, is their easy mouldability, or plasticity. The electrotechnical industry is one of mass-production, for which the technique of the processing of plastics is highly suitable.

To this is to be added the fact that it is quite easy to give a glossy appearance, coloured if necessary, to objects made from plastics.

¹) By this it is meant that the material suffers little from electrical discharges between electrodes placed on the surface, especially when the surface is covered more or less with an electrolyte.

These last two properties, plasticity of the material and good finish of the product, are reasons why plastics are also used where the electrical properties are not of such great importance, as in the manufacture of radio cabinets, telephones, door-knobs, lamp fittings, etc.

In this article something will first be said about the molecular structure of plastics, this being



followed by a survey of the principal moulding materials and their specific properties. We shall then briefly discuss the methods employed in manufacturing articles and components from plastics. In conclusion a number of examples are mentioned of the use of such articles, mainly in the electro-technical industry.

Macro-molecular substances

A substance that plays an important part in the preparation of plastics is phenol, the structural formula of which is given here in a simplified form. Compared with that of the substances dealt with below, the phenol molecule is simple in structure.



It is a micro-molecular substance with a molecule consisting of 13 atoms. Plastics, on the other hand, are all macro-molecular, being built up in very large molecules each consisting of 1000 or more chemically bound atoms. As an example the structure of a phenol-formaldehyde molecule is shown in *fig. 1*, indicating at the same time by what reaction this substance is formed. Plastics have recently been developed having molecules containing 10,000 and even 100,000 atoms.

In the synthetic production of plastics one starts from micro-molecular substances, and in the choice of these it is necessary to consider the functionality of the reactants, by which is understood the number of hydrogen atoms or reactive groups of the original elements taking part in the formation of macro-molecular compounds. The reactants must be chosen so that after the first reaction has ceased there is still sufficient functionality left. A couple of examples may serve to explain what is meant.

In the esterification of acetic acid and ethyl alcohol each reactant has the functionality 1 (it is a so-called 1:1 reaction) and when the ethyl acetate is formed the reaction is completed; macro-molecules cannot arise in this way.

When glycol and acetic acid, respectively bifunc-

tional and monofunctional, are brought together, the reaction comes to an end by the formation of the di-acetate.

If, however, the acid is also bifunctional, possibilities are then opened for further reactions. An example of such a 2:2 reaction is that between phthalic acid and glycol, which can be represented by the following formula:

When two molecules of phthalic acid have reacted upon one molecule of glycol the result is a molecule which has two reactive groups. Two of these new molecules will then in turn react upon a glycol molecule. This goes on and on and leads to the formation of polymers. The original phthalic acid molecules are joined together by CH_2 links.

This manner of producing plastics is called the condensation method, where, in the bonding of two different molecules, a simple separation product (in this case water) is eliminated.

Another form of condensation is obtained when a trifunctional substance is caused to react upon a bifunctional substance, for instance glycerine with phthalic acid. We can imagine that here again polymers are formed as in the 2:2 reaction, but in these chains alcohol groups are left which

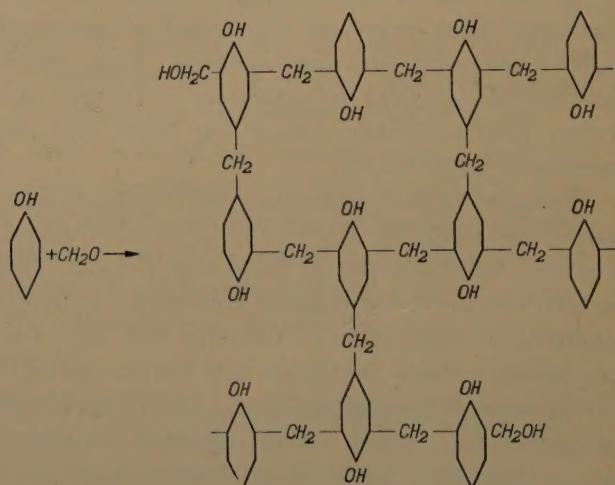


Fig. 1. The formation of phenol-formaldehyde resin. This representation is only diagrammatic. One must imagine the benzene nuclei as being three-dimensional and coupled together in irregular order.

have not yet been esterified. If now there is sufficient phthalic acid present, two hydroxyl groups of different chains will be esterified by one molecule of phthalic acid. In this manner the polymers are coupled together to form three-dimensional struc-

tures. This transition is characteristic for the 3:2 reaction.

A second method of producing entirely synthetic macro-molecular substances is the polymerization method. Here small molecules of the same kind are joined together and without elimination of by-products. To give an example of this we will take the preparation of polystyrene, a product of great importance nowadays. The formulae relating to this case are given in *fig. 2*. The basic material for the macro-molecule is styrene (*a*). This molecule is activated either by means of catalysts or by irradiation or heating, as a result of which it is strongly agitated and the double bond opens out as indicated in *fig. 2b*. When this activated molecule is brought together with another molecule a reaction takes place (*c*). The activated molecule then created can react in turn with a new molecule of styrene. The ultimate result is a polymer (*d*). In this way one can obtain from styrene the macro-molecular polystyrene; many other substances possessing a $-C^H=CH_2$ group are also capable of polymerization.

It is particularly in the field of polymerization that great advances have been made during the last 20 years, resulting in the development of a number of valuable products such as polyvinyl acetate, polyvinyl chloride, polyvinylidene chloride, polyvinyl alcohol, polyethylene, polyacrylic acid and methacrylic acid esters.

An important property of macro-molecular substances is their strong cohesion, much stronger than that found with micro-molecular compounds. This may be illustrated by comparing micro- and macro-molecules with grains of sand and wads of cotton wool. Grains of sand packed together show very little cohesion, whereas wads of cotton wool are not easily parted.

The molecules of a substance attract each other through forces of an electrical nature, called van der Waals forces, which increase in strength as the molecules become larger; these give to macro-molecules a mutual cohesion much stronger than that of micro-molecules.

Many plastics are made in the form of fibres (e.g. nylon yarns). It appears that the strongest fibres are obtained when the linear polymer molecules are orientated longitudinally in the fibre direction. This is in fact always the case with natural fibres.

The two kinds of macro-molecular substances — the two-dimensional (polymer) molecules and the three-dimensional molecules — behave very differently when heated. The first category usually becomes plastic when the temperature is raised

sufficiently and solidifies again upon cooling down, apparently no chemical conversion taking place in the plasticizing. This group of plastics are called thermoplastics. On the other hand the substances formed from three-dimensional macro-molecules belong to the group of thermosetting plastics. These materials first become plastic upon being heated but after a time set hard and remain so after cooling down. It is not possible to make them plastic again by further heating.

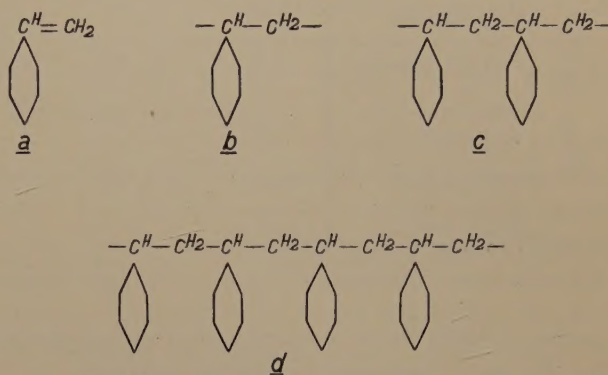


Fig. 2. The formation of polystyrene. *a*) Styrene. *b*) Activated styrene molecule. *c*) Two activated styrene molecules joined together. *d*) Polystyrene.

The difference just mentioned between two-dimensional and three-dimensional macro-molecular structures is not an invariable rule. If the mutual cohesive force of two-dimensional macro-molecules is very strong then the temperature at which the material can be made plastic is so high that disintegration takes place before that temperature is reached. Cellulose is a known example of this.

The principal moulding materials and their specific properties

When an article is to be made from a plastic the material has to be put into a mould or press to give it the right shape. The material prepared for this is called the moulding powder. The moulding powders most used are:

- 1) the thermosetting powders: phenolic resins, amino-plastics, polyesters and some silicones;
- 2) the thermoplastic powders: various cellulose derivatives, polyamides, polystyrene, polyethylene, polydichlorostyrene, polyvinylidene chloride, polyvinyl acetate, polyvinyl butyrate, vinyl chloride and various mixed polymers, acrylate resins and silicones.

These differ greatly in their physical and chemical properties. Furthermore it is possible to vary these properties by the addition of suitable fillers.

In order to give a survey of the properties of these plastics we shall classify them under several

Table I. Properties of some plastics.

		Specific weight	Shock-bending test $\text{N}\cdot\text{m}/\text{m}^2$ ²⁾	Notch toughness $\text{N}\cdot\text{m}/\text{m}^2$	Distortion temperature in °C.	Insulating resistance $\text{ohm}\cdot\text{cm}$	Dielectric constant at 1000 c/s	$10^4 \times \tan \delta$ at 1000 c/s	Disruptive strength in kV/mm
Thermo-setting plastics	Phenol plastics with various fillers	1.35-1.8	$7\text{-}30 \times 10^3$	$1.5\text{-}25 \times 10^3$	150-170	$10^9\text{-}10^{12}$	5	100-500	10-30
	Amino-plastics	1.5	7×10^3	1.7×10^3	120	10^{12}	5-7	500	15
Thermoplastics	Polystyrene	1.05	20×10^3	5×10^3	65-100	$>10^{12}$	2.5-2.7	0.5-5	20-28
	Polyethylene	0.92	—	—	50	$>10^{12}$	2.25-2.3	3-5	16-19
	Polyvinyl chloride	1.38	175×10^3	5×10^3	65	10^{12}	4.9-5.6	1000	7-16
	Polymethacrylic acid esters	1.18	25×10^3	—	65-100	$>10^{12}$	3.2-3.4	500-600	20
	Polyamides	1.08-1.14	$>150 \times 10^3$	10×10^3	65	10^{12}	4-5	200-500	14-16
	Ethyl cellulose	1.08-1.18	—	—	40-90	$>10^{12}$	2.5-3.5	170-360	16-24

²⁾ 1 N (newton) = 10^5 dyne, $1 \text{ N}\cdot\text{m}/\text{m}^2 = 1.02 \times 10^{-3} \text{ kg cm}/\text{cm}^2$.

groups. In *table I* some numerical data are tabulated for the most important moulding materials.

Phenolic resins

Phenolic resins (for example "Philite") are synthetically composed from raw materials obtained from coke and tar. The admixed fillers (wood-flour, mica, asbestos and suchlike) often constitute half the total weight of the moulding powders and considerably influence their properties. Powders of such a composition are widely used for making radio cabinets, telephones, door-handles, etc.

Phenolic resins without fillers are much used in glues, varnishes, etc.

Amino-plastics

Among the amino-plastics are urea- and melamine formaldehyde, which are often used mixed together to give a material that has good electrical properties and which can be made in a great variety of reasonably stable colours. This material is used instead of phenoplast in cases where a good non-tracking quality is required or where the products have to be made with bright colours.

Cellulose derivatives

The kinds of cellulose widely used in industry are: cellulose nitrate (made from wood cellulose or cotton fibres treated with sulphuric acid and nitric acid and softened with camphor), cellulose acetate (prepared from cotton fibres with sulphuric acid, acetic acid and acetic anhydride), cellulose aceto-butyrate (made from cotton fibres treated with acetic acid, acetic anhydride and butyric acid) and ethyl cellulose (likewise made from cotton

fibres treated with soda and ethyl chloride).

Plastics with a cellulose base are exceptionally suitable for mass production and are used for the manufacture of articles of a widely divergent nature. Cellulose nitrate is best known under the name of celluloid.

Vinyl compounds

The best known vinyl compounds are: polyvinyl acetate, polyvinyl chloride, polyvinylidene chloride and polyvinyl alcohol.

Polyvinyl acetate serves for the cementing of glass, paper and other material.

Polyvinyl chloride serves as a synthetic rubber; since softeners are used in the preparation of this substance, materials of different hardness can be made.

Under the polyvinyl compounds there are also polystyrene, polyethylene and acrylate resin.

Polystyrene is as clear as glass. It is used, inter alia, for all sorts of cheap jewellery. In the electro-technical industry it is used because it is an exceptionally good insulating material with a very low loss factor and possessing, moreover, the favourable property of absorbing very little water in humid surroundings.

A relatively new, somewhat leathery, flexible and transparent material is polyethylene. Owing to its very good electrical properties it is used instead of guttapercha in the covering of submarine cables. For the same reason it is much used in radar technique.

Acrylate resin (polymethyl acrylic acid ester) is an important kind of resin. This material in itself

is completely colourless and perfectly transparent, more so than any other material. In recent years it has been used more and more for making windows in aircraft. Further, it is used for optical glasses, artificial eyes and teeth, etc.

Polyamides

It was not until 1940 that polyamides came to the fore. They form a very strong and tough material which so far has found its place on the market mainly as a fibre material (nylon yarns).

Silicones

Some silicones are thermosetting materials and others are thermoplastic. They form a series of materials (liquids, greases, rubber-like and resinous substances) all of which have this in common that although they are not organic substances in their structure they nevertheless show a great resemblance to them. The main links of the molecule chains are formed by silicon and oxygen atoms. The side chains, derived from the silicon atoms, bear methyl groups or other groups containing carbon atoms. It is also possible to link via an oxygen atom a silicon atom from one chain with a silicon atom from another chain.

The most striking property of all these compounds is their resistance to high temperatures, for instance up to 300-400 °C, at which temperatures organic substances are sure to be decomposed. This is highly important because such is not the case with any of the plastics so far described; at high temperatures, owing to chemical disintegration accompanied by the separation of carbon, they are transformed into brownish black and useless masses³). Silicones are therefore especially employed in cases where high temperatures occur: the liquids and greases for lubricating parts of machinery which get very hot, the rubber silicones for the insulation of wires exposed to high temperatures and the resins as insulating material in engines. In the lacquer industry these resins are used for making lacquers for painting ovens, flues, radiators and suchlike.

The silicones have good electrical properties. It is also of importance that they are water-repellent; an object that has been immersed in a silicon solution will not be wetted by contact with water.

³) During the second World War in the U.S.A. another plastic material was developed, called "Teflon" (polytetrafluoro ethylene), which can be heated up to 400° C without any noticeable decline in its properties. This material, which resembles stiff leather, has very remarkable properties, the most important of which is its chemical inertness. Thus it is not affected by any organic liquid nor by any corrosive reactants such as, for instance, aqua regia. This material opens up new possibilities of great importance in technical engineering.

Moulding of the articles

It has already been pointed out that many applications of plastics have been made possible owing to the ease with which the products made therefrom can be given any desired shape. Use is thereby made of the plastic properties of the material, which show to advantage when it is heated. The mass is pressed at a high temperature when in a more or less liquid state, to give it a certain shape.

The shaping of articles from thermosetting masses is done in moulds under pressure. We need not go into this in detail here because it has already been discussed in two articles in this journal dealing with "Philite"⁴).

The mould is usually of steel and made in two parts. A certain weighed quantity of the mass is placed between the two halves of the mould, which are then heated to about 160 °C and pressed together, this being mostly done with the aid of hydraulic presses. Some products turned out in this manner are illustrated in fig. 3.

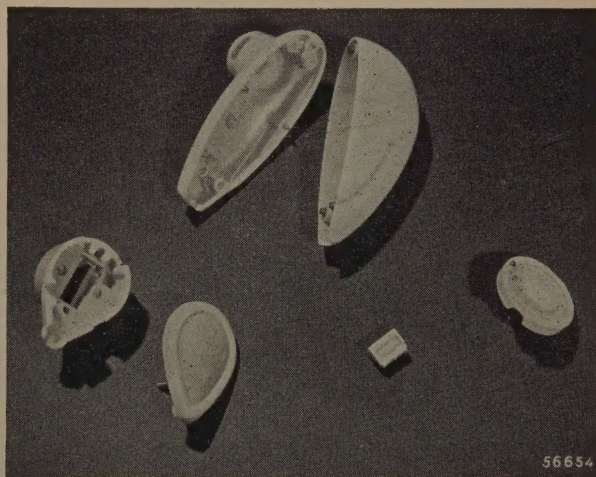


Fig. 3. Parts of a "Philishave" dryshaver made of urea-formaldehyde. This material allows of the objects being given an attractive light colour.

Obviously one cannot in this way make articles of every desired shape. Products made from thermosetting moulding masses must be capable of being taken out of the mould; after the shaping, the top and bottom halves of the mould have to be drawn away from the product in opposite directions. Sometimes this can be arranged by deviating from the conventional shape of the article (compare for instance the handle of a teacup made from a plastic material with that of a china cup). A product

⁴) R. Houwink, Properties and application of artificial resin products, Philips Techn. Rev. 1, 257-263, 1936; L. L. C. Polis, "Philite" as a structural material, Philips Techn. Rev. 3, 9-16, 1938.

that does not come away immediately but which can still be moulded in a mould consisting of two halves is one that has a single screw thread, such as a jampot lid; when the mould is opened the product is left in the half of the mould which shapes the thread, but it can be removed by unscrewing it.

Laminated materials take a special place in the moulding technique. In a certain respect these are comparable to sheets of plywood. In the manufacture of these materials paper, tissue or wood veneer is used in the form of sheets of about $1\text{ m} \times 1\text{ m}$ (about $3' \times 3'$). These sheets are saturated with resin and pressed together between hot plates, thus producing a resinous mass interspersed with layers of paper, tissue or wood.

In practice this is done by passing a strip of paper or fabric first through a bath of resin in solution and then through a long oven to remove the solvents and partly harden the resin. The strip is then cut into pieces which are stacked one upon the other and then pressed between flat plates. The materials produced in this manner from phenolic plastics are called resin-bounded papers or sheets.

In the moulding of articles from thermoplastic masses different methods of manufacture are employed, but these too are based upon the plastic properties of the material at a high temperature.

Account is taken of the fact that owing to the nature of their macro-molecules these materials do not set hard when heated. With these materials the products are shaped by injection, extrusion, pressing and blowing.

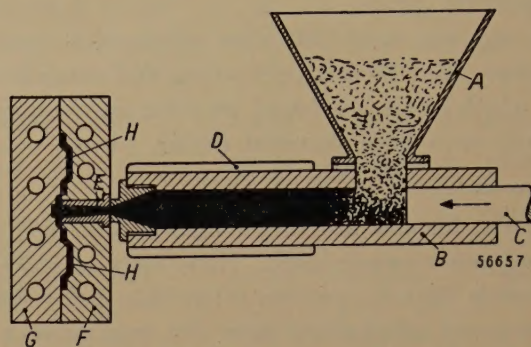


Fig. 4. The process of injecting thermoplastic material. *A* hopper charged with the moulding mass, *B* cylinder, *C* plunger, *D* heating element, *E* injection channel, *F* and *G* dies of the mould with cooling channels, *H* two products (small trays).

The process of injection is illustrated in *fig. 4*, a diagrammatic representation of a machine used in this process. The moulding material is fed into a heated cylinder with a constricted opening at one end. This cylinder is heated to such a temperature as to soften the material. The softened material is injected into the mould by means of a plunger fitting into the cylinder.

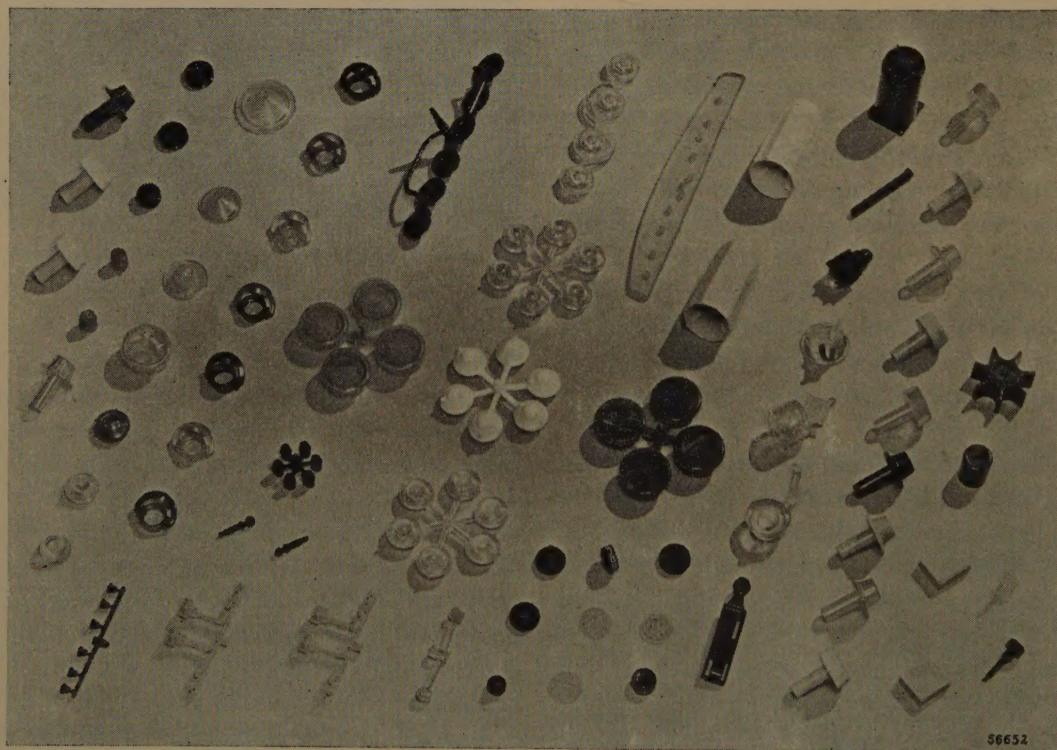


Fig. 5. A number of articles produced by the injection method. The raw material used for some of these is polystyrene and for others polymethacrylic acid esters ("Plexiglas").

Often the mould is cooled. When the cavity in the mould is filled the plunger is stopped. *Fig. 5* shows a number of articles produced by the injection method.

Rods, tubes, etc. are made by the method of extrusion or squirting. This method is illustrated

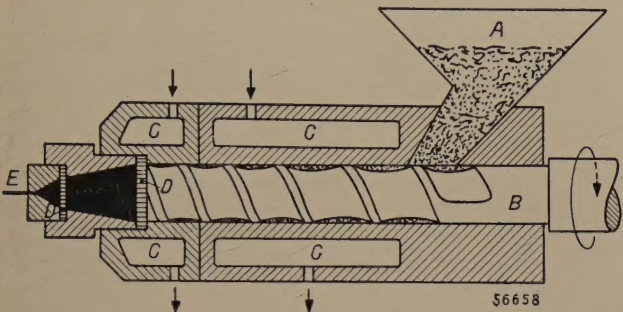


Fig. 6. The extrusion of thermoplastic material. *A* hopper charged with the moulding mass, *B* worm spindle, *C* heating elements, *D* sieves, *E* extruded product.

in *fig. 6*. The material is placed in a cold hopper and transported through a cylinder by means of a worm spindle. The cylinder is heated higher and higher as the material passes through it. In order to get a homogeneous mass the softened material is often pressed through one or two sieves. The end of the cylinder has a constricted opening. The soft mass passes through the opening into the air and sets hard.

The shape of the outlet determines whether rods (round opening) or tapes and plates (rectangular opening) or tubes (annular opening) are produced. It is also possible to apply a coating of the material to copper wire for use as flex or cable.

When the pressing process is applied with thermoplastic masses it is done in much the same way as with thermosetting material. Bottom and top dies are used, both heated. Since at the elevated temperature the mass remains soft, it is necessary to cool the mould while it is still closed. Pressing is applied, inter alia, in the manufacture of plates, although these are usually made by the injection method.

In the blowing method one starts with plates or tubes in the form which they have already been

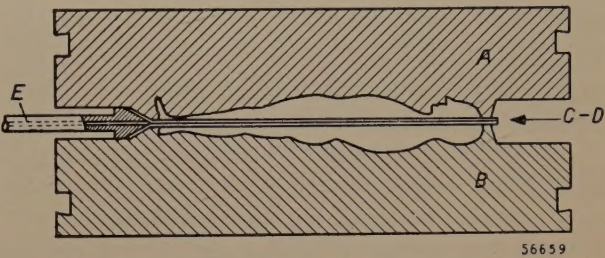


Fig. 7. The blowing method used in the moulding of thermoplastic material. *A* and *B* top and bottom dies, *C* and *D* two heated plates of the material (not yet moulded), *E* channel through which air is forced in between the plates.

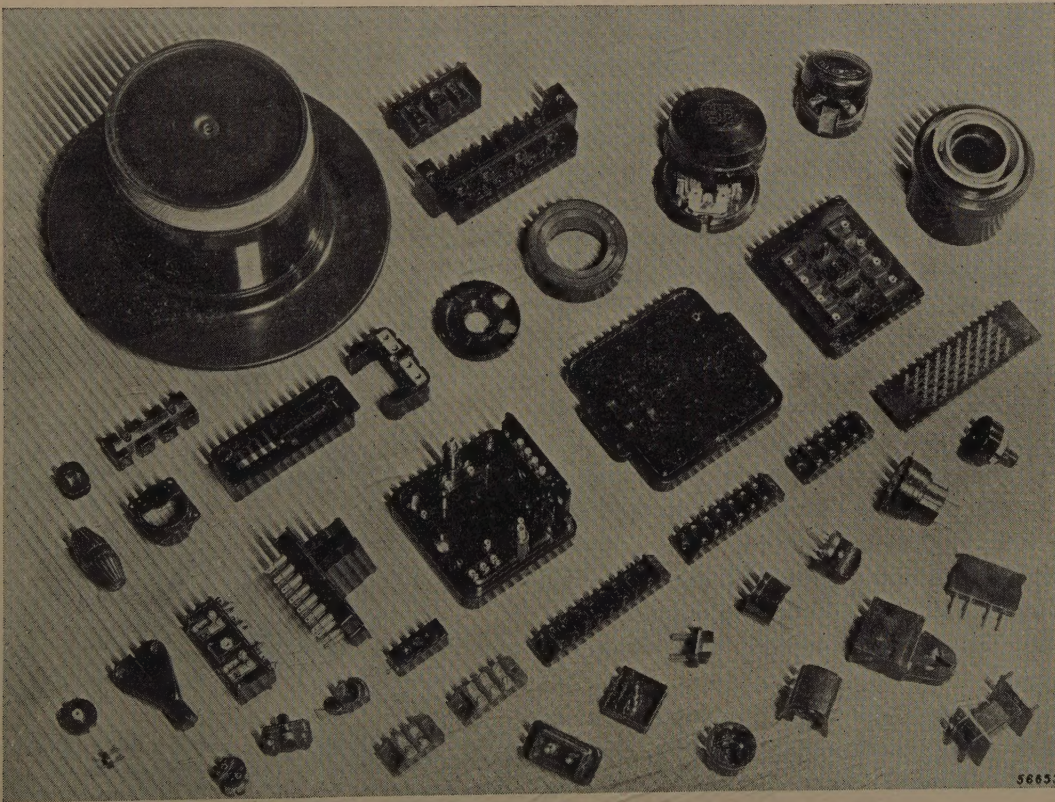


Fig. 8. Component parts of electrotechnical apparatus, all press-moulded from phenol-formaldehyde ("Philite").

given by injection, extrusion or pressing. This is illustrated in *fig. 7*. For instance two hot plates of material are placed between the top and bottom dies of a mould. Between the plates a hollow needle is inserted through which air is blown. The plates are thus blown apart and given the shape of the mould. The manufacture of celluloid dolls is an example of the application of the blowing method. An advantage of this method of working is that no steel dies are needed because only low pressures have to be applied.

In conclusion some examples are given of the use of plastics as constructional material for electrotechnical apparatus.

Applications

From table I it is seen that in the thermosetting category there are materials with greatly divergent properties. Among the thermoplastic materials included in this table are those most used in the manufacture of electrotechnical apparatus; as these, too, show widely divergent mechanical and electrical properties, care is needed in the selection of the most suitable material for each application.

In *fig. 8* a number of component parts of electro-technical apparatus are illustrated, all moulded from phenol-formaldehyde ("Philite"). The moulding masses used for these products differ considerably in composition. Some of these articles, for instance, are used in X-ray apparatus and for that purpose they are often required to have a high dielectric strength (30 kV/mm at 90 °C), while at the same time they must be resistant to the effects of hot oil. Furthermore, the material must be easily mouldable in view of the often complicated and precise form of the parts of such apparatus. These articles are therefore made from a kind of "Philite" which has a high dielectric strength, which fully answers these requirements and has a much higher breakdown voltage than the normal "Philite".

Polyethylene and polystyrene are particularly noticeable in the table on account of their low dielectric losses. This explains why these two materials are so frequently used in the electrotechnical industry. Polyethylene is much used as a covering for cables carrying high-frequency currents, whilst polystyrene is used for all sorts of apparatus or components having to answer high electrical requirements.

The low softening point of polystyrene is a drawback, but by using substituted styrene the chemical industry has already succeeded in producing polymers with higher softening points and still retaining the good electrical properties.

In *figs. 9* and *10* some coil bodies with adjusting screws are illustrated. Polystyrene was chosen as the material for these articles on account of its excellent electrical properties. Often, however, this material is chosen only because it is easily shaped by the injection or extrusion processes.

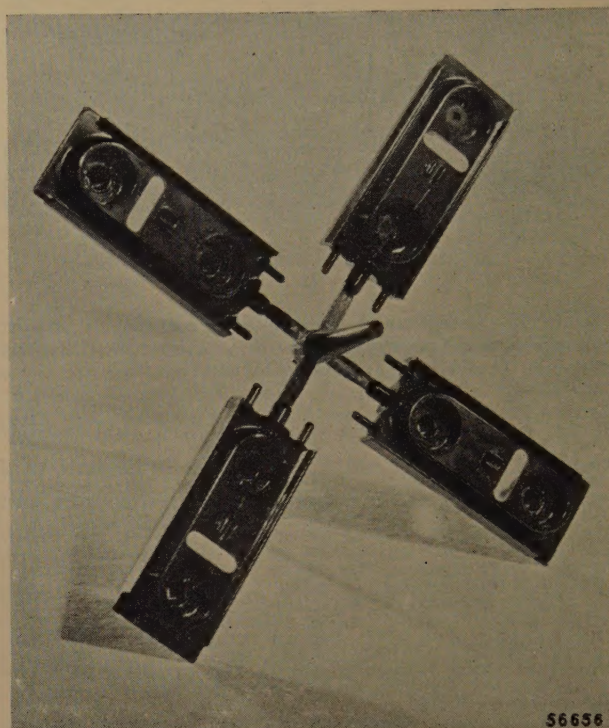


Fig. 9. Coil bodies of polystyrene. This shows the workpiece as produced by the injection method. It consists of four coil bodies which are subsequently pinched off the common holder.

Polyvinyl chloride is used on a large scale for spraying wire used for the manufacture of flexes and flexible connections, examples of which are illustrated in *fig. 11*.

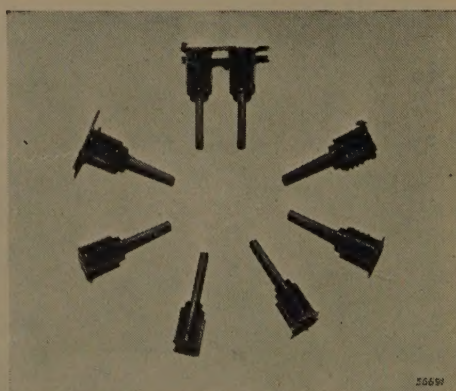


Fig. 10. Adjusting screws for the coil bodies illustrated in *fig. 9*. These screws (in the illustration they are $\frac{3}{4}$ of the actual size) comprise a core of "Ferroxcube" with a holder of polystyrene; they serve for adjusting the self-inductance of the coils, ultimately mounted in the coil bodies. These screws, too, are produced by the injection method.

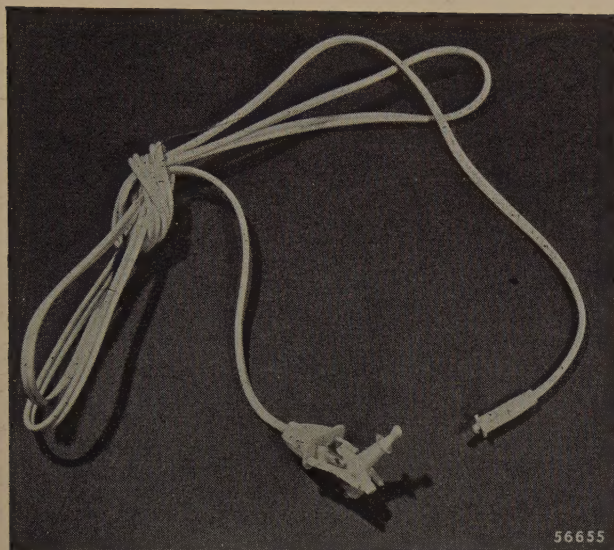


Fig. 11. A flex made of polyvinyl chloride. The flex itself is extruded, whilst the sleeve and the plug are injected. This flex belongs to the "Philishave" dryshaver, some parts of which are illustrated in fig. 3.

The optical properties of polymethacrylic acid esters are utilized for instance in the manufacture of lenses and prisms. The high index of refraction and the small light absorption make this material highly suitable for this purpose. Some of the articles illustrated in fig. 5 are made from this material, whilst fig. 12 shows an example of a product made from this material in the electrotechnical industry.

The examples given are confined to some of those belonging to the field of mass production, but this is only a selection taken at random from a multiplicity of applications. For the sake of completeness it is to be mentioned that in the electrotechnical industry plastics are used not only as raw materials for mass-produced articles but also for all kinds of individual purposes where it is not so much a matter of easy processing as of certain combinations of

properties. Thus it often happens that for one particular component of a single apparatus use is made of one of the typical characteristics offered by the family of plastics (including silicons and "Teflon") in such great variety.

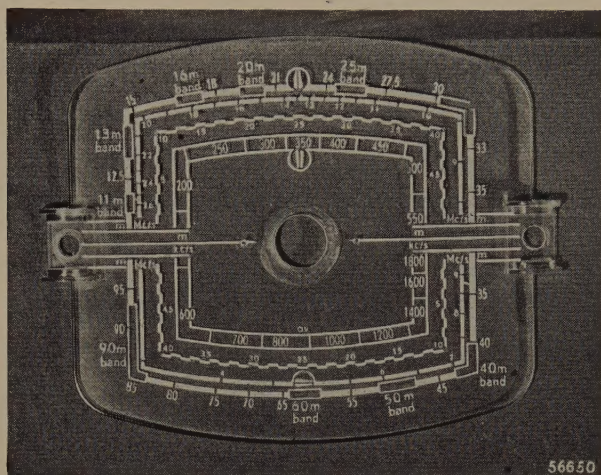


Fig. 12. A station dial for a radio set, made from polymethacrylic acid ester ("Plexiglas") according to the injection method.

Summary. Just as in many other fields, plastics are extensively applied in the electrotechnical industry as constructional materials for all kinds of apparatus. Often they are used for these purposes on account of their good electrical properties, whilst in other cases it is their easy mouldability and the good finish that can be given to the products which count most. It is very often possible to synthesize these materials with the properties required for a particular purpose. Of the methods employed in the formation of the macro-molecules characterizing all plastics, the condensation and polymerization methods are discussed. Use is made not only of thermosetting moulding materials but also, and to an increasing extent, of thermoplastics materials. The most important materials and their specific properties are dealt with briefly. A table gives an idea of the great diversity of these properties. In the moulding of articles from thermoplastic material four methods are employed: injection, extrusion, pressing and blowing. Finally a number of applications of plastics in the electrotechnical field are discussed.

AN OPERATION WITNESSED BY 200 SPECTATORS



At the occasion of the *Dies* Celebration at the University of Leiden (Netherlands) a demonstration was given on February 5th 1949 in order to enable a large audience to witness the televising of a surgical operation. The above photograph was taken during this operation, that was carried out by Prof. Dr. W. F. Suermondt, of the above-mentioned University, and his main assistant Dr. J. Kweekel. As can be seen from the photograph the pick-up device — an iconoscope — is situated next to the surgeon and directed towards the patient. In front of the iconoscope one of the two stands, each carrying three mercury lamps, can be seen. These lamps are water-cooled so that no trouble is experienced with the heat developed. In addition, incandescent lamps fixed to the ceiling were used for the general illumination. — The amplified video signals from the iconoscope were transmitted over a cable to a lecture hall where the image was projected onto two screens of $1\text{ m} \times 1.3\text{ m}$ (about $3' \times 4'$). Each half of the audience, consisting in total of over 200 spectators, were easily able to follow the operation. At the receiving end two units comprising a cathode-ray tube and an optical projection system as described in this Review ¹⁾ were used.

¹⁾ Projection-television receiver, I. The optical system for the projection, by P. M. van Alphen and H. Rinia, and II. The cathode-ray tube, by J. de Gier, Philips Techn. Rev. 10, 69-78, 1948 (No. 3) and 97-104, 1948 (No. 4).

INFLUENCE OF LIGHT UPON PLANTS

by R. van der VEEN.

581.1.035

Plants need light! By and large this is undoubtedly true, but a closer investigation shows that this cannot be accepted without reserve. The most favourable intensity and composition of the light for the feeding, the shaping and the flowering of a plant is not always the same, and as regards the duration of the exposure to light it appears that dark periods are often just as essential for flowering as light periods. All such factors should be considered in order to arrive at a method of irradiating plants with artificial light that is most suitable for a certain object.

The fact that light is one of the most important factors in the life of a plant is commonly recognized. In a non-tropical climate the intensity of the light received from the sun during the winter months is, for many plants, inadequate for a strong development. It is therefore understandable that both the nurseryman and the lover of plants often tries to promote the growth and development of his plants by means of artificial light.

Light, however, has many different effects upon plants. Artificial lighting can therefore only be applied successfully when one first makes quite sure what result is to be expected and knows how it should be applied to attain the object in view. Attention has to be paid both to the intensity and duration of the irradiation as well as to the composition of the light used.

In this article some of the effects of light upon the life of a plant will be discussed, namely those of:

- 1) light for the feeding,
- 2) light for the shaping,
- 3) light for the flowering.

Light for assimilation or photosynthesis

One of the first to carry out systematic research into the processes of plant life was Jan Ingen Housz, a Dutchman. His principal book "Experiments upon vegetables", the result of some hundreds of experiments, was published in 1779 while he was in England. There it is stated that green plants correct bad air when they receive sunlight. Later on it appeared that this purification consists in the absorption of carbon dioxide and the excretion of oxygen.

Through his experiments Ingen Housz became the discoverer of the photosynthesis of plants. This photosynthesis is to be regarded as the feeding process of the plants. Disregarding water, only an extremely small fraction of the material from which a plant is built up comes from the soil. By far the greater part is assimilated in the form of carbon

dioxide and converted into carbohydrates. At the same time, however, as Ingen Housz demonstrated, another process is taking place, the respiration of the plants. In this process the substances formed by photosynthesis are burnt, carbon dioxide being excreted and oxygen absorbed.

Photosynthesis is a strongly endothermic reaction. The energy required for this is supplied by the light. Investigations have shown that only the visible part of the spectrum can act as the source of energy. Ultra-violet and infra-red rays are both injurious to plants. The various colours of the visible spectrum do not have the same effect upon photosynthesis. Taking assimilation of CO_2 in red light ($\lambda = 6500 \text{ \AA}$) as 100, according to Gabrielsen that in yellow light ($\lambda = 5450 \text{ \AA}$) is about 60 and that in blue light ($\lambda = 4400 \text{ \AA}$) only 38 ¹⁾. The absorption of light energy takes place through the chlorophyll granules, the corpuscles which give a green colour to the stems and leaves.

In addition to the composition of light, the intensity of the radiation also plays a great part in photosynthesis. As a general rule the greater the intensity the greater is the photosynthesis, but there are a number of factors restricting the validity of this rule.

The first of these factors is the temperature. The manner in which the growth of a plant is affected by the intensity of radiation at any temperature can be found experimentally, somewhat different results being obtained according to the kind of plant. In *fig. 1* some curves are given taken from experiments carried out by Bolas with tomatoes ²⁾. It is seen that the growth of a plant reaches a maximum at a certain intensity of irradiation, this

¹⁾ The fact that the strongest photosynthesis takes place under red light accounts also for the relatively favourable effect of neon lamps for irradiating plants. The wavelength of the radiation from these lamps lies between 6000 and 7000 \AA . See J. W. M. Roodenburg and G. Zecher, Irradiation of plants with neon light, Philips Techn. Rev. 1, 193-191, 1936.

²⁾ B. D. Bolas, Cheshunt Annual Report 19, 84, 1933.

optimum intensity increasing as the temperature rises. With an intensity of 2000 lux a temperature of 18 °C is most favourable, whilst with intensities of 7500 and 10,500 lux the most favourable temperatures are respectively 25 and 30 °C.

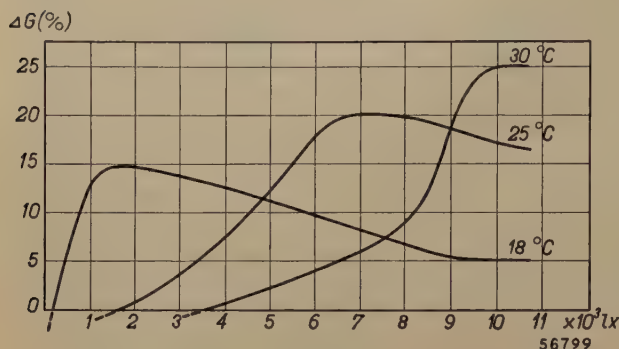


Fig. 1. The growth of a plant as function of the intensity of light at three temperatures (taken from Bolas). On the vertical axis the increase ΔG of the "dry weight" of the plant in 7 hours is set out as a percentage. This test was taken with tomatoes.

In such investigations one has to bear in mind that both photosynthesis and respiration play a part in the growth of a plant. It is however possible to separate these two factors, since if a plant is placed in the dark, or given a small dose of chloroform, photosynthesis ceases while respiration continues. When thus determining separately the degree of photosynthesis it appears that at any temperatures only a certain maximum photosynthesis is possible. Once this has been reached photosynthesis is not increased by a greater intensity of light. The higher the temperature, the greater the maximum photosynthesis, within certain limits. Further, it has been found that as the temperature is raised also respiration increases.

Fig. 2 shows the relation between photosynthesis and the intensity of radiation for different levels of temperature. In these graphs the numerical values, which differ according to the plant species, have been omitted. From the trend of the curves it is to be seen that no purpose is served by giving a plant more than a certain amount of light at a certain temperature. But it is also undesirable to raise the temperature higher than that which is suitable for a certain intensity of light, because then, as already stated, respiration is intensified and this is a process which counteracts photosynthesis, as far as the increase of weight of the plant is concerned.

By irradiating with certain, rather small intensities one can by experiment find a point where respiration and photosynthesis are balanced. This is called the compensation point. Fig. 1 shows

with what intensity of light, for three given temperatures, this compensation point is reached in the case of the tomato.

If plants are to be made to grow, the irradiation of light should be such that the difference between photosynthesis and respiration is positive. In many cases irradiation can be applied only during a part of the 24 hours. The intensity of the light must then lie far above the compensation point, since respiration is continuous.

The higher the temperature, the higher is the compensation point. More light is then required to compensate respiration, since this increases at higher temperatures.

At a temperature of 20 °C and with a light intensity of 500 lux one is, in most cases, above the compensation point. The plants then certainly grow but often very slowly. If rapid growth is required, a light intensity of 1500 to 3000 lux is necessary for most plants. Such an intensity is easily reached with high-power lamps placed close above the plants.

If, however, incandescent lamps are used for this purpose, the heat from the radiation will as a rule be so great as to injure the plants. This can be avoided by using a water filter between the lamps and the plants, this filter holding back the infra-red rays. This method, however, has so many objections that it is preferable to use lamps which radiate very little heat and which can be placed close above the plants without having to take any special precautions. Fluorescent lamps (MCF/U lamps) are highly suitable for this purpose.

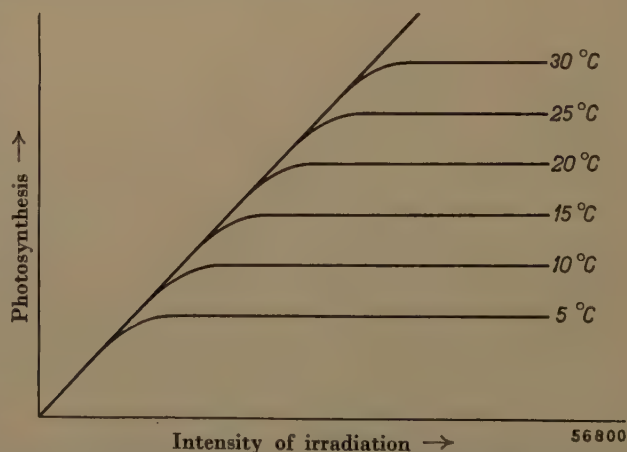


Fig. 2. Graphs representing the relation between photosynthesis and the intensity of irradiation at various temperatures.

Owing to the relatively low power of these lamps a large number are required (about 5 per square metre) and this makes the installation rather expensive. Nevertheless it is undoubtedly of advantage for many nurserymen to apply this

method for intensively lighting some of the space in their glasshouses. Seeds can then be sown already in the winter in this part of the glasshouses and as a result the nurseryman can begin in the spring with better developed plants. Most plants can easily be raised a month in advance in this way.

that cannot be discussed in general terms because in this respect the various kinds of plants react to light in a different manner. We can therefore only make a few observations and give an example.

In the dark, plants grow tall and spindly, the foliage remains small and the colour yellowish. The



Fig. 3. Artificial lighting of a glasshouse in which Gloxinias are being raised. The lighting is from 40 W MCF/U lamps of the "daylight" type.

Fig. 3 shows the lighting installation of a glasshouse in which gloxinia plants have been raised. Fig. 4 demonstrates the difference between boxes of plants raised without artificial light, with moderate lighting and under a strong light.

This method of lighting also makes it possible to raise young plants during the winter months in a shed or room instead of in a glasshouse. For instance, cornflowers sown on 15th January in a cellar heated to 21 °C were already flowering on 25th February. In such cases the saving in fuel for heating a glasshouse will usually not outweigh the cost of lighting and heating the cellar, so that this method is still expensive.

Light for shaping

Light has also a considerable effect upon the shape in which a plant grows³⁾. This is a subject, however,

plants are then said to be etiolated⁴⁾. Further, under red and yellow light many plants shoot upwards and these are likewise said to be etiolated although they turn green. Since the light from incandescent lamps is mainly composed of yellow and red rays, with regard to plants raised under this light one speaks of incandescent-light etiolation.

Generally speaking one finds in a plant two substances which absorb light of a certain wavelength and use the absorbed energy for the growth and development of the plant, namely chlorophyll and carotene. Chlorophyll, as already stated, serves especially for photosynthesis and absorbs mainly red rays. Carotene affects the shape of the plant (length, foliage, etc.) and absorbs particularly blue rays.

Plants raised under blue light are usually shorter but stronger than those grown under white light. For normal development all plants need a certain amount of blue light, more in some cases than in others. *Mirabilis* is one of the plants needing a

³⁾ This influence of light upon the development of plants has already been discussed in two previous articles. See R. van der Veen, Forcing tulips with artificial light, *Philips Techn. Rev.* **10**, 282-285, 1949 (No. 9); Storing seed potatoes in artificially-lighted cellars, *Philips Techn. Rev.* **10**, 318-322, 1949 (No. 10).

⁴⁾ etiolate = to become pale.

great deal of blue radiation. *Fig. 5* shows some specimens of this plant raised under light of a different composition, one under red light with about 10% blue, another under yellow light with about 10% blue, and a third specimen under blue light with about 20% yellow and red, all irradiated with practically the same total energy. Only the last specimen was well developed.

day plants. Others will never flower if they get only short days of light, these requiring long periods (14 hours or more per day); they are called long-day plants. Finally there is a group of plants that are indifferent to the length of daylight. The whole of this phenomenon is termed photoperiodicity. In the field of photoperiodism there are a multitude of contradictions; as regards the



Fig. 4. The effect of lighting upon Gloxinias. On the three boxes of plants in the foreground the rearmost was exposed only to sunlight. The left-hand one was given additional weak artificial light during November and December; the right-hand one was irradiated with strong artificial light during those two months. The photo was taken in the beginning of February.

This example goes to show how great a difference there can be in the effect of different kinds of light upon the development of a plant.

Light for flowering

The flowering of several kinds of plants depends entirely upon the time during which they have been exposed to light. As regards flowering, the intensity of the light, so important for growth, is of minor importance.

With respect to the need of light, the varieties of plants can be placed in three groups. There are plants which only flower when exposed to light during a certain number of short days (10 hours light or less per day) and these are called short-

mechanism of the actions of light in that respect one is still entirely in the dark ⁵⁾. We shall, therefore, not go into this too deeply and will confine our considerations to a few aspects of this problem.

As already remarked, the influence of the length of daylight is not bound directly to high intensities of light. Consequently a short winter day for a

⁵⁾ The results of some experiments would seem to show that under the influence of light a certain hormone may be formed which stimulates flowering and without which the plant cannot flower. The symptoms would indicate that this hormone is formed in the leaves. So long as a short-day plant is exposed to a long day it will develop vegetatively. When, however, a leaf is taken from a plant exposed to a short day and grafted upon such a plant the latter will flower. Apparently the hormone referred to is transported from the grafted leaf to the point of growth on the main stem of the plant.

plant can often be turned into a long day by adding a few extra hours of artificial lighting of 50 lux.

Winter-flowering Begonias give blooms when the days are short, whereas when the days are long the buds only develop vegetatively, so that big but not flowering plants are formed. When incandescent lamps are kept burning during the winter months in begonia glasshouses flowering is checked



Fig. 5. Three *Mirabilis* plants raised respectively under red, yellow and blue light. Only the last one developed properly.

and the buds develop vegetatively, which is just what the nurseryman desires, because in the winter season he wants plenty of material for cuttings. In the same way *Poinsettias* and *Euphorbias* are raised in the autumn and winter for cuttings.

The results of various experiments show that what takes place in the dark period is something quite different from that taking place during the period of light. Hamner ⁶⁾ distinguishes the factor A, the process during exposure to light, from the factor B, the process taking place in the dark. These together yield the factor C which causes the plants to flower.

The factor A probably has something to do with the photosynthesis of the plant. The flower-inducing effect of the length of day presumably takes place in the chlorophyll. Several established facts point to this.

The soya bean, a typical short-day plant, needs, to start flowering, a dark period of at least 10 hours with a light period of at least 4 and at most 14 hours, with a decided optimum of 10 hours. The minimum intensity of light that has to be given during the light period is 1000 lux. Given this intensity of light for 5 hours daily, the plant yields a number of blooms. With higher intensities, thus promoting photosynthesis, the number of blooms increases up to a certain maximum. The duration of the exposure to light must, however, exceed the lower limit of 4 hours, regardless of the intensity used.

The minimum intensity of 1000 lux is understandable when one bears in mind that (with the optimum temperature for growth of the soya bean) this is about the limit at which an excess of photosynthesis begins. The effect that assimilation during the period of light has upon flowering is evident from the smaller number of blooms formed when photosynthesis is checked during the period of exposure to light by reducing the carbon dioxide content of the air. Further, Borthwick and Parker ⁷⁾ have succeeded in getting twice as many blooms from a soya bean by increasing the carbon dioxide content of the air from about 0.03% to 1% ⁸⁾.

Observations made with other short-day plants agree, on the whole, with what has been found in the case of the soya bean.

Remarkable discoveries have also been made from a study of long-day plants. Went ⁹⁾ found that with a period of 10 hours light the *Baeria* plant is just stopped from flowering, regardless whether the intensity of the light is 2000 or 15,000 lux, whereas any additional exposure, with weak or strong light, beyond these 10 hours causes the plant to flower equally well ¹⁰⁾.

Went has also investigated the effect of the

⁷⁾ H. A. Borthwick and M. W. Parker, *Bot. Gaz.* **102**, 256, 1940.

⁸⁾ The photosynthesis of a plant can also be checked by reducing the number of leaves. When three fourths of the number of leaves on a soya bean plant are removed still just as many blooms develop. From this it is to be concluded that Hamner's factor A is dependent upon the photosynthesis per surface unit and that the total photosynthesis matters comparatively little.

⁹⁾ F. W. Went, *J. Bot.* **32**, 1, 1945.

¹⁰⁾ By weak is meant here an intensity of 2000 lux. This is still a fairly high intensity of light compared with that which interferes with the effect of the period of darkness.

⁶⁾ K. C. B. Hamner, *Bot. Gaz.* **101**, 658, 1940.

composition of the light to which long-day plants are exposed. He found that red light greatly stimulates bloom development, whilst yellow and blue light do so to a less degree and green light has no effect at all at an intensity of 2500 lux. This is yet another indication that the effect of daylight upon these plants has something to do with the photosynthesis, at least with the chlorophyll.

Other investigations have also shown that the colour of the light influences the flowering of a plant.

Klebs found that blue light checks the flowering of *Sempervivum*, whilst on the other hand red light promotes this process. Lettuce flowers quickly under red light, whereas under blue light nice firm heads are formed. Cornflowers come into bloom under red, yellow and blue light, but under green light they bloom very slowly. In all these cases the blooms differed in colour, red light giving small blooms with a faded colour whereas blue light gave blooms of the brightest blue.

Quite frequently irradiation with blue light results in a strong formation of anthocyanin. The stems and the leaf veins then turn red, owing to the red colour of the anthocyanin predominating over the green. Flowers which owe their colour to anthocyanin therefore often have a deeper colour when cultivated under blue light.

Most long-day plants also flower when exposed to continuous light; they do not need a dark period at all. In the case of short-day plants, however, the length of the dark period is just as essential for flowering as the period of light, and one might therefore just as well call them long-night plants.

Short-day plants need an undisturbed night. If a night of 16 hours is interrupted in the middle by a quarter of an hour's light this has the effect of breaking it up into two nights of 8 hours, with the result that the plant does not flower. The extent of this effect depends upon the total amount of light given during that interruption. As a rule, within certain limits, two minutes with 10,000 lux has the same effect as 20 minutes with 1000 lux or 200 minutes with 100 lux.

Even light of a very low intensity (100 lux) thus has its effect. Advantage is taken of this in practice, in order to prevent short-day plants flowering, by switching on a number of low-power incandescent lamps in the glasshouse during the dark period. With the low intensity of the light from these lamps there can be no question of excessive photosynthesis. The factor B is sensitive to light but, in contrast with factor A, has nothing to do with photosynthesis.

The effect of the period of light upon plants is not confined to the development of blooms, for there are also other phenomena influenced by the length

of day. As an example may be mentioned the growth of the stem. But although stem growth and flowering are both influenced by the length of day, there are probably two quite independent reactions at play; various observations point in that direction.

In the case of *Rudbeckia* for instance a long day (14 hours light) is beneficial for stem growth and flowering, whereas when the day is short the plant does not flower and bears only leaf rosettes. When young plants are exposed to light for a number of long days their stems begin to grow at once. Upon this being followed by short-day exposure stem growth stops and a rosette is formed at the top of the stem. The remarkable fact is that blooms then begin to develop on this rosette. Apparently bloom development is induced by the long-day treatment and the effect of this continues even after the stem growth has been brought to a standstill.

The effect that long days have upon stem growth is also to be noticed in the case of the strawberry, which is a short-day plant. The flowering process starts during the short days of the autumn but it is not until the long days arrive that the plant blooms and bears fruit. During the short days the leaf stems are very short, but as the days lengthen they grow longer and ultimately the flowers open. But during the long days no new flowering is started. Thus in the case of this plant it can also be said that the influence of the length of day upon flowering is quite different from that upon the stems.

The foregoing serves to show in broad lines and very briefly the stage which has been reached in the problem of the photoperiodism of plants. The general picture is still very confused. The theories formed by some investigators to explain the mechanism of the action of light upon plants are not very convincing. Much more research will be needed before a satisfactory insight into this matter can be obtained.

These investigations are of importance for the biologist studying the laws applying in natural life, but they are also of importance for the nurseryman, who can only utilize natural and artificial light successfully when he knows how various kinds of plants react to such light.

Since the various kinds of plants make entirely different demands upon the nature of the light it is difficult to find a lamp of universal use for their irradiation. Mercury lamps, which give mainly blue light, and neon and sodium lamps with their predominantly red and yellow radiation respectively, do

not by any means provide the best solution in all cases. In this respect fluorescent lamps offer more possibilities. With these lamps there is a choice between the "warm white" type with its spectrum mainly in the red and yellow, and the "daylight" type in which much blue occurs. By a combination of "warm white" and "daylight" lamps it is also possible to obtain intermediate colours.

For good plant development irradiation with exclusively red and blue light would probably suffice, the red light for promoting photosynthesis and the blue light for the shaping of the plant. Fluorescent lamps with a mixture of cadmium borate and magnesium tungstate would be the most

suitable, but it would have to be investigated what ratio of these two phosphors offers the most economical solution for each kind of plant.

Summary: During the winter months, for many plants, there is too little sunlight for strong development. Attempts are then made to stimulate growth by means of artificial light. Intensification of the light, however, is not favourable under all circumstances. It is necessary for a nurseryman to know exactly the various effects that light has upon plants. In this article the importance of light is discussed in connection with the feeding, the shaping and the flowering of the plants. Attention has to be paid both to the intensity and duration of the irradiation and also to the composition of the light. Different kinds of plants react differently. The effect upon flowering is determined for the greater part by the photoperiodicity, i.e. the ratio of the periods of alternating light and darkness. It is clearly shown that the solution of the problems discussed is still only in an initial stage.

AN AUTOMATIC BRAKING DEVICE FOR X-RAY APPARATUS

by J. M. CONSTABLE *).

621.313.334.07-59;621.386.14

The operation of modern X-ray equipment for mass chest survey must in most respects be made automatic in order to enable the examination of hundreds of persons per hour. An interesting problem in the design of such equipment is the provision of means for rapid adjustment to the individual requirements of each examinee. Differences in chest size necessitate different exposure times. An article published earlier in this Review described the automatic timer which solved this problem. Differences in height require an adjustment of the vertical position of the apparatus for each examinee. The present article describes how in performing this adjustment by means of an electric motor the movement of the apparatus can be rapidly interrupted in order to avoid overshooting the required position.

The problem of decelerating or rapidly interrupting a movement is rather old. Many braking devices have been designed for the purpose in order to meet the requirements of every special case.

In vehicles it is a common practice to use the motor itself as a brake, i.e. to make it produce a torque opposite to the actual rotation of the wheels. This method is especially useful when applied to electric motors, as their torque can be reversed in a simple way. Moreover, in this case the kinetic energy to be dissipated need not be converted into heat but in some cases may be recuperated in the form of electric energy supplied back to the power line. The economic importance of this feature is evident in the case of electric trains travelling over mountainous routes. Other merits of the method as applied to electric motors are the reliability and good controllability of the braking action. These features account for its frequent use in elevators and cranes.

As a further advantage of the principle we may mention that no mechanical braking equipment is required. A limitation, however, will in many cases be imposed by the fact that the braking torque produced by the motor cannot exceed the starting torque to any significant extent.

After this short prelude, we can turn to the special case we have in mind.

The apparatus for series production of miniature X-ray photographs, described in this Review some time ago ¹⁾, is provided with a mechanism allowing vertical adjustment of the X-ray tube and photographic camera in accordance with the height of the examinee. The weight of all moving parts is approximately counterbalanced by springs. Nevertheless, the vertical adjustment of the apparatus,

if performed by hand, in addition to being tedious and time-consuming, may draw heavily on the physical strength of the operating personnel, who in many cases must cope with 200 or more examinees per hour. Therefore an electric motor which can be switched on and off simply by pressing and releasing a lever actuating one of two micro-switches is provided to move the apparatus up and down.

Rapid starting and stopping is of prime importance in this adjustment in order that too much time is not lost with every examinee. Since the torque requirement for stopping is essentially the same as that for starting, using the motor itself as a brake is a logical solution to the braking problem. Moreover, a previously mentioned advantage of the method — that no special parts adding weight to the apparatus are required — was particularly important for our purpose, as every effort was made to cut down the weight of the apparatus in order to make it easily transportable.

It is evident that the interruption of the movement in this case must be made automatic. The motor and the moving parts must come to a stop as soon as possible after the operating lever is released, without interference from the personnel and regardless of whether the movement is "up" or "down".

Fig. 1 shows in schematic fashion the solution applied for our apparatus. The motor is of the single-phase induction type. As is well known, the stator winding of such a motor does not produce a starting torque but will make the rotor run in either direction when once started. For starting, an auxiliary winding on the stator is provided, which is placed at an angle of 90° with respect to the main winding and is energized with a phase difference of approx. 90° with respect to this winding. When the rotor has reached full speed the auxiliary winding is cut out. The starting torque may be reversed by simply reversing the polarity of either the auxiliary

*) Formerly North American Philips Co., Inc., New York, N.Y.

¹⁾ H. J. Di Giovanni, W. Kes and K. Lowitzsch, A transportable X-ray apparatus for mass chest survey, Philips Techn. Review 10, 105-113, 1948/49 (No. 4).

winding or the main winding. After this brief recapitulation, the wiring diagram in fig. 1 will readily be understood.

Re_1 , Re_2 , Re_3 are relays with a number of contacts r_1 , r_2^1 , r_2^2 , \dots ; r_3^1 , \dots , all indicated in the initial position (coil of relay de-energized). M_1 and

preventing the motor from actually starting rotation in the opposite sense ²⁾.

Let us now consider four different situations.

I) The operating lever O on "neutral", rotor at rest.

All coils of relays and windings of motor are de-energized.

II) O on "down", hence M_1 closed, rotor still at rest.

Momentarily, all three relays are energized. But the contacts are so designed that r_3^2 and r_2^2 open first and very quickly; hence Re_2 is

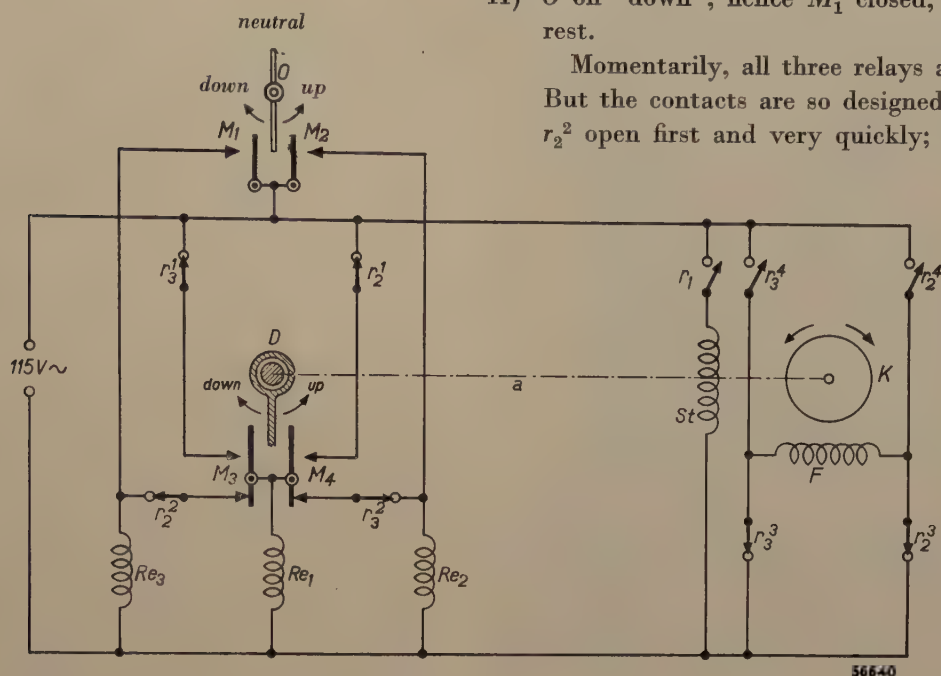


Fig. 1. Schematic circuit diagram of the braking device. K single-phase induction motor, with main winding F and auxiliary (starting) winding St ; D magnetic drag mounted on motor shaft a ; O operating lever; M_1 - M_4 micro-switches; Re_1 - Re_3 coils of relays; r_1 contact actuated by Re_1 ; r_2^1 , r_2^2 , r_2^3 , r_2^4 contacts actuated by Re_2 ; r_3^1 , r_3^2 , r_3^3 , r_3^4 contacts actuated by Re_3 . All contacts are indicated in their initial position (coil of relay de-energized).

M_2 are two micro-switches actuated by the operating lever. M_3 and M_4 are two additional micro-switches actuated by the magnetic drag (D) on the shaft of the rotor. In fig. 2 the drag is shown separately. The shaft carries a small permanent magnet (A); a copper ring supported by a ball bearing is placed around this magnet with a small separation distance. When the shaft is rotating eddy currents are induced in the ring, tending to make it rotate with the shaft. Hence, the switching lever fixed to the ring is turned over in much the same way as by a friction coupling between ring and shaft, but with the significant difference that this "friction" disappears when the motor comes to a stop: the switching lever then falls back to its initial position. These properties of the magnetic drag make it possible not only to energize the motor automatically in an opposite sense after the operating lever is released, but also to interrupt this energizing current as soon as the movement is stopped, thus

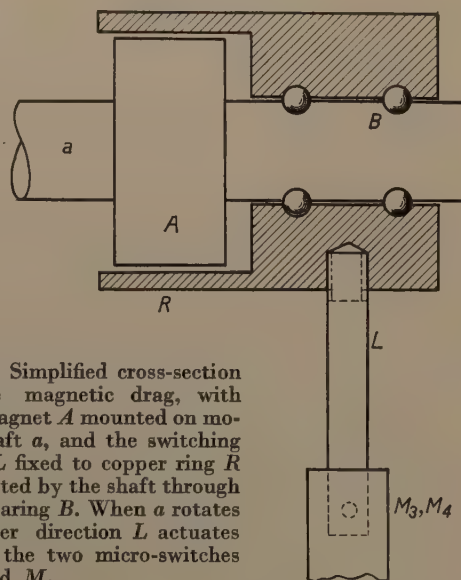


Fig. 2. Simplified cross-section of the magnetic drag, with ring magnet A mounted on motor shaft a , and the switching lever L fixed to copper ring R supported by the shaft through ball bearing B . When a rotates in either direction L actuates one of the two micro-switches M_3 and M_4 .

²⁾ A similar braking device, operated by a magnetic drag, has been designed earlier for various machine tools, as e.g. punching and shearing machines.

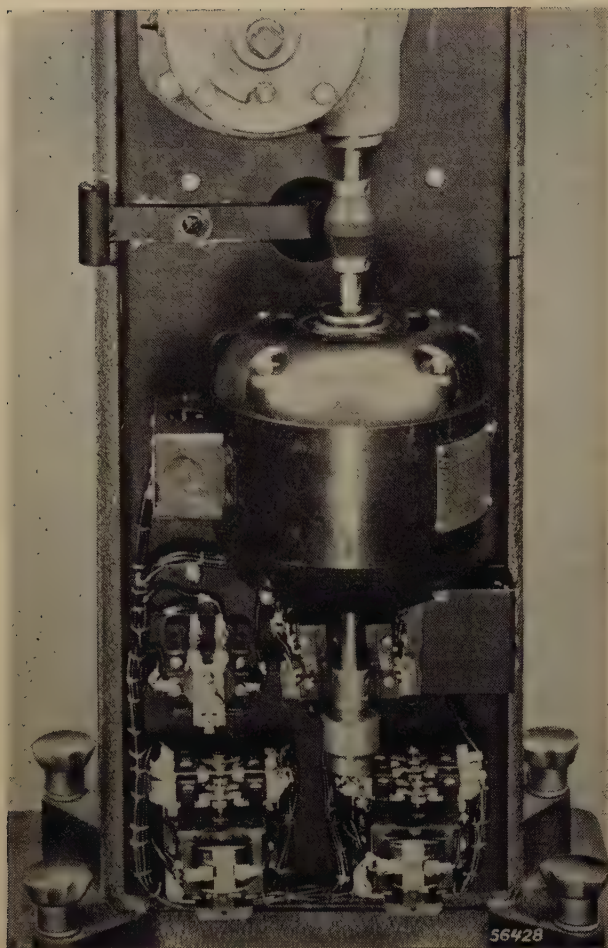


Fig. 3. Showing the motor and relay assembly in one of the pedestals of the X-ray apparatus (cf. the article quoted in footnote 1)). The ring of the magnetic drag and the two micro-switches are clearly visible on and next to the lower end of the motor shaft.

immediately de-energized and r_2^2 closes again (while r_3^2 remains open). Now Re_1 is energized via r_2^2 and M_3 , hence the starting winding St is energized. As the main winding F is energized via r_2^3 and r_3^4 , a torque is produced in the "down" sense.

- III) O held on "down", rotor rotating in "down" sense. The magnetic drag is turned over, so M_3 is actuated, Re_1 is de-energized (r_3^1 being open) and St is cut out; Re_3 remains energized, so does F ; rotor continues running "down".
- IV) O again on "neutral", whereby M_1 is opened, rotor still running "down", M_3 remains actuated. Re_3 de-energized; Re_2 energized via r_3^2 , M_4 , M_3 , r_3^1 , hence main winding F energized via r_3^3 and r_2^4 , i.e. in the sense opposite to situation II. Moreover, Re_1 is energized via M_3 , r_3^1 , hence the starting winding St is energized also and the desired torque in the "up"

sense is produced, strongly braking the still continuing "down" rotation.

When the rotor comes to a stop the magnetic drag is released, M_3 returns to its initial position and all coils and windings are de-energized; situation as in I.

Analogous considerations apply to the case where O is first set on "up" and again on "neutral" after a sufficient upward displacement of the apparatus has been obtained.

The micro-switches M_1 and M_2 are closed by the operating lever O through a limit bar assembly which ensures returning the lever to "neutral" when the upper or lower limits of travel of the apparatus have been reached.

The total weight of all moving parts is 200 lbs. In a position of medium height this weight is exactly counterbalanced by the springs, in higher positions it is not completely balanced and in lower positions it is overbalanced. The motor, which rotates at 1750 revolutions per minute, is capable of lifting the apparatus from every position at a rate of 1 inch in 1 second. Without any braking device, i.e. relying only on the friction of the moving parts, in general the motor would not come to rest before about 20-30 revolutions after the operating lever is released, thus in many cases overshooting the desired position of the apparatus. Under the most unfavourable circumstances — when the apparatus moves downward from the extreme upper position — it would in some cases (when friction is low) even continue down due to its incompletely balanced weight until it reached some medium position. With the braking device described above, however, regardless of the position of the apparatus when the operating lever is released, the motor comes to a stop within 2 or 3 revolutions, corresponding to an apparatus displacement of not more than 0.1 inch.

Fig. 3 shows a photograph of the combination of relays mounted on the motor frame.

Summary. In the Philips apparatus for series production of miniature X-ray photographs the height of the X-ray tube and camera is adjusted by means of an electric motor in accordance with the height of the examinee. The motor is operated with a single control lever for up and down movement. When the lever is returned to neutral one of a pair of micro-switches, actuated by a magnetic drag mounted on the motor shaft, causes a set of relays to change the energizing of the motor in such a way that a torque opposite to the still continuing motion is produced. This braking torque brings the motor to a stop within 2 or 3 revolutions, thus avoiding the risk of overshooting the desired position of the apparatus. The magnetic drag returns to its initial position as soon as the rotor comes to a standstill and prevents the rotor from actually starting rotation in the opposite direction.

DARK-ROOM LIGHTING

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To speak of dark-room lighting, as the photographer desires it, seems paradoxical; how can a room be illuminated so that it still remains dark? The paradox disappears when it is borne in mind that the conceptions of "dark" and "light" are used here for two different organs of perception. The room has to be dark, or at least sufficiently so for the photographic material, and it has to be light, or again at least sufficiently so for the human eye. These two requirements can indeed be compatible one with the other provided there is sufficient difference in the spectral sensitivity of the two organs. This article deals with the fundamental possibilities for dark-room lighting existing by reason of these considerations, and their practical realization is discussed for various purposes.

The problem of dark-room lighting in photography amounts to this, that it is desired to give the eyes sufficient light for performing a certain task without that light causing any noticeable blackening of the photographic material.

If the general sensitivity of the photographic material is relatively small the problem can easily be solved by a suitable choice of the level of illumination. Otherwise the object in view can still be reached provided there is sufficient difference between the spectral sensitivity of the photographic material and that of the eye, in which case a suitable spectral distribution of the light used must be chosen.

As a matter of fact all practical systems of dark-room lighting are based on these principles. When we come to consider, however, normal photographic negative material in particular, disregarding for a moment positive papers, X-ray films and suchlike, then we find that the lighting of the dark room has become more and more difficult. The photographic industry is aiming at making the negative emulsions more and more sensitive so that good photographs can be taken with little light or with very short exposures; at the same time attempts are being made to make the spectral sensitivity curve of the emulsions approximate as far as possible to that of the eye, so as to reproduce the various colours with the correct shades of grey. As a result the differences between the eye and the negative will gradually disappear and we may therefore say somewhat paradoxically that the aim of the modern photographic industry in regard to negative material seems to be directed towards rendering dark-room lighting impossible.

In the case of some "panchromatic" emulsions this object has already been fairly well attained. Such emulsions have to be developed in almost complete darkness (unless prior to or during the development the sensitivity of the emulsion is reduced by means of a so-called desensitizer, which

however also has its disadvantages). Now in order to avoid having to sit in the dark during the whole developing process the method of tank developing is used for panchromatic films. The developer is contained in a tank, which can be closed in a light-proof manner, and in which the film is placed while the room is in darkness or only very weakly illuminated, the film then being taken out again after a certain time has expired; once the tank has been closed the photographer can turn on the lights and carry on with some other work. But this solution of the problem of dark-room lighting is not really what is desired, for it is just the developing process itself that the photographer most desires to watch, and to do so he has to examine the film or plate several times during that process, thus of necessity exposing it to some light. Something similar applies in the photographic industry where these emulsions are made: if the continuous processes of manufacture are to be checked at all then the emulsion must be exposed to a certain, though very small, amount of light.

In this article we shall consider what possibilities still exist for the lighting of a dark room in this sense while developing various modern emulsions. We shall then deal with the practical realization of these possibilities with different kinds of dark-room safe-lights, and also briefly discuss the dark-room lighting for handling positive papers (which is fundamentally simpler).

From the foregoing it appears that the investigation into the possibilities of dark-room lighting will amount to an investigation of the sensitivity of the eye for light on the one hand and of the photographic material, in this case the negative emulsion, on the other. We shall have to ask ourselves the questions:

- 1) What amount of light does the eye need in the dark room?
- 2) How much light can the emulsion safely stand?

The fundamental difficulty outlined above can be avoided by applying a so-called image converter. By means of infra-red rays an image of the object to be viewed is cast upon a screen covered with a certain phosphorescent substance or with an electron-emitting layer. In the first case the screen, which must previously have been activated by irradiation with a radio-active preparation, produces a visible "fluorescent picture" directly, whilst in the second case the electrons emitted produce a visible picture on a normal fluorescent screen placed farther away ¹⁾.

When a film or plate with a panchromatic emulsion, which is insensitive to the infra-red rays, is being examined in this way no trouble whatever is experienced from the fact that its spectral sensitivity in the visible zone so strongly resembles that of the eye, and one can raise the "illumination" to a high level.

As far as we know this method has not yet been applied in the practice of photography.

What the eye requires

In order to decide how much light the eye needs we must first establish what the eye has to do and under what circumstances it has to perform that duty.

To exercise control over the developing process, which we take to be the purpose of the dark-room lighting, the photographer examines the partly developed negative in transmitted light to see whether there is sufficient contrast of the details in the light and dark parts. Since the contrast sensitivity as a rule diminishes with the level of illumination, when working in the dark room the photographer will certainly not be able to observe just as fine contrasts in the negative as can be seen in daylight. But this is not necessary. It has been found that the process of development can be followed quite well if, for instance, one can perceive the difference between two densities of the order of 1.0 and 1.1 ²⁾.

There are, however, also parts in the negative having a very much smaller density, say 0.1, and since these parts let ten times as much light through as those where the density is 1.1, there will be a certain amount of glare, so that the observer's contrast sensitivity in the darker parts is adversely affected.

The quicker the negative can be examined, the better it will be protected against fogging. The time that the photographer must allow himself to examine and judge the negative can be taken as 7

¹⁾ G. Holst, J. H. de Boer, M. C. Teves and C. F. Veenemans, *Physica* 1, 297-305, 1934.
²⁾ When light with an intensity I_0 is thrown upon an exposed plate and behind the plate the intensity is only I , the density is defined as $D = \log I_0/I$. In what follows, the density above the so-called natural fogging of the negative is meant. In this case I_0 means the intensity behind a part of the negative on which no light has fallen when the photograph was taken.

seconds, to which is to be added 3 seconds before that for the eye to adapt itself to the mean level of brightness behind the negative.

Van Kreveld and Van Liempt ³⁾ have determined experimentally the brightness that an observer needs under these conditions — thus with the glare referred to and a total observation time of 10 seconds — to be just able to distinguish the two densities 1.0 and 1.1, likewise the two densities 1.0 and 1.2 and also 1.0 and 1.3 The experiments were carried out with different kinds of monochromatic light (wavelengths $\lambda = 5086, 5890, 6438$ and $> 6800 \text{ \AA}$). The results, averaged over a large number of observations by different persons, are represented in *table I* by the required radiance in $\text{W/m}^2 \cdot \text{steradian}$ at the part of the negative where the density is 1.0. The corresponding irradiance in W/m^2 at the back of the negative is shown in the next column. It is assumed that the negative emulsion fully diffuses the transmitted light, and account is taken of the light-absorption of the non-reduced silver bromide (not yet removed by fixing), which averages for various kinds of plates and films about 60 %.

For the complete control of the development of the negative the photographer will normally have to examine it twice for contrast of details.

Table I. The minimum illumination required to permit the distinction of various contrasts (first column) in a photographic negative under the conditions given, in the case of monochromatic light of different wavelengths.

Densities to be distinguished	Wave-length in \AA	Required radiance (at the place with density 1.0) $10^{-3} \text{ W/m}^2 \cdot \text{sterad.}$	Irradiance on back of negative 10^{-3} W/m^2	Quantity of radiation when examining negative twice 10^{-3} Wsec/m^2
1.0-1.1	5086	0.14	1.1	22
	5890	0.18	1.4	28
	6438	1.0	8	160
	> 6800	7.7	60	1200
1.0-1.2	5086	0.06	0.45	9
	5890	0.02	0.15	3
	6438	0.25	2	40
	> 6800	1.8	14	280
1.0-1.3	5086	0.0025	0.02	0.4
	5890	0.005	0.04	0.8
	6438	0.013	0.1	2
	> 6800	(0.4)	(3)	(60)

³⁾ A. van Kreveld and J. A. M. van Liempt, Measurements on dark-room illumination, *Physica* 5, 345-373, 1938.

It is assumed that during the rest of the time the negative is not exposed to any light in the dark room (the developing bath being covered over for instance). Altogether, therefore, the negative will have to be exposed for 20 seconds to the irradiance

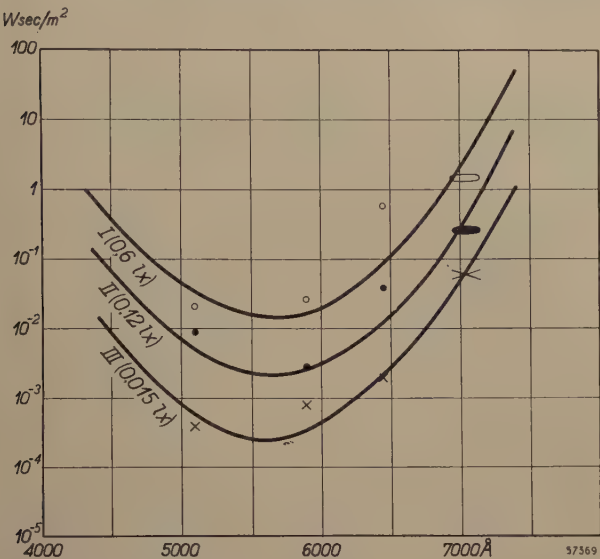


Fig. 1 To distinguish the difference between two densities under monochromatic light one needs for each wavelength a certain irradiance in W/m^2 on the back of the negative. Curves have been plotted representing the energy in $Wsec/m^2$ corresponding thereto with an exposure of 20 seconds for distinguishing the densities 1.0 and 1.1 (curve I), 1.0 and 1.2 (curve II) and 1.0 and 1.3 (curve III). (Measured in lux the necessary irradiance is practically the same for all wavelengths; this is indicated against the curves.)

quoted in table I. The number of $Wsec/m^2$ (quantity of radiation) calculated in this way is indicated in the last column of the table and plotted in fig. 1 as a function of the wavelength for the three different contrast sensitivities in the first column of table I.

The experimental results can also be expressed in the required brightness (c/m^2), illumination (lux) and exposure (luxseconds). The figures given in table I, each for a certain wavelength, then have to be multiplied by the relative luminosity factor corresponding to the wavelength (and by the mechanical equivalent of light 683 lm/W). We have not introduced here the visual quantities because for comparison with the effect of the radiation upon the emulsions, which will be our next step, the eye sensitivity has in any case to be eliminated from the figures. It is to be observed here, however, that if the visual quantities are used (employing the normal eye-sensitivity curve for high brightnesses) one will arrive at the unforeseen result that the requisite numbers of c/m^2 , lux and luxseconds are roughly independent of the wavelength of the light used. For the three contrast observations considered in table I it appears that about 0.6, 0.12 and 0.015 lux respectively are required.

This independency is to be so interpreted that the contrast observation and the perception of brightness depend upon the wavelength in much about the same way: the points of measurement in fig. 1 lie on curves showing about the same

trend as the reciprocal relative luminosity factor. Since this similarity is not likely to be a mere matter of chance, the relative luminosity curve has therefore in fact been taken as being representative for the rather strongly scattered points of measurements.

As regards the difference between the relative luminosity curves with low and with high levels of brightness, something will be said about this farther on.

What the emulsion can stand

What happens in the negative when it is exposed to light while being developed in the dark room? Following the line of thought of Van Kreveld and Van Liempt³⁾, let us consider the density curve of the negative. This gives the relation between the quantity of radiation H that has fallen upon a point of the film and the resultant density D at that point. When the $\log H$ is plotted along the abscissa this relation, which also depends upon the kind of emulsion and the manner of developing, is represented approximately by a straight line, such as line 1 in fig. 2. The slope of this line, thus $dD/d \log H$, provides a measure for the richness of contrast for the negative, namely the difference in density that will result from a certain difference in brightness between two parts of the object photographed.

Suppose that line 1 in fig. 2 is the density curve $D(H)$ of a negative developed in absolute darkness. If instead of being developed in the dark the negative receives a small dose of light H_0 equal over the whole surface then the density at each point will increase to a value

$$D_1(H) = D(H + H_0) (1)$$

Thus the negative gets a new (apparent) density curve which can be constructed from line 1 in fig. 2 and is represented by line 2. It is seen that the slope of line 2 at each value of H is smaller

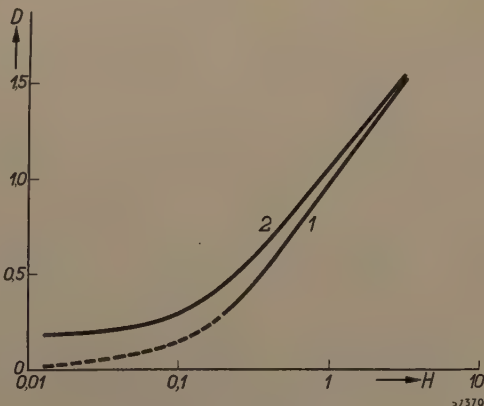


Fig. 2. Line 1 is the density curve $D(H)$ of a normal negative developed in absolute darkness. Line 2 is the "apparent" density curve $D_1(H)$ of the same negative fogged during developing by a small extra exposure (H_0).

than that of line *I*. In other words, the extra exposure of the negative results in a deterioration of the contrasts over the whole line. The relative change x of the contrast is

$$x = \frac{dD_1/d \log H - dD/d \log H}{dD/d \log H} \dots (2)$$

With the aid of (1) this can be written as

$$x = H_0 \frac{d^2D}{dH^2} \bigg/ \frac{dD}{dH}.$$

Experience teaches that in the case of a normal negative a contrast reduction x of maximum 10 % can be allowed without the negative suffering any appreciable loss in quality. The question is now with what value of the extra exposure H_0 one can still be sure that the permissible value of x is not exceeded.

A simple answer can be given thanks to the fact that x has a maximum value for a certain density. This can easily be understood if one studies the density curve (line *I*) in fig. 2. In the straight part this has an equation of the form

$$D = a \log H + b \dots (2)$$

(a and b are constants). From this it follows that:

$$\frac{d^2D}{dH^2} \bigg/ \frac{dD}{dH} = -\frac{1}{H},$$

$$x = -H_0/H.$$

As H increases, the contrast reduction thus approaches zero. On the other hand, for very small values of H , where the density curve deviates considerably from the straight line, the curve can be represented by an equation of the form:

$$D = cH + d \dots (3)$$

(c and d are again constants). From this it follows that $d^2D/dH^2 = 0$, so that in this part of the density curve the contrast reduction likewise equals nil. The value of x must therefore pass through a maximum between the very small and the very large values of H .

With the density curves usually found in practice this maximum mostly lies round about the density 0.3. Since equation (2) already holds to a good approximation here, the maximum contrast reduction taking place in the negative is

$$x_{\max} = H_0/H_{0.3},$$

where $H_{0.3}$ signifies the exposure required to blacken

the film to a density of 0.3 on the emulsion concerned. Substituting for x_{\max} the above-mentioned permissible value of 10%, we see that the extra exposure (H_0) of the negative while it is being developed is limited by the condition

$$H_0 \leq 0.1 H_{0.3} \dots (4)$$

So far we have been disregarding the possibility that the light under which the photograph is taken (H) and that to which the negative is exposed while being developed (H_0) may have a different spectral composition. In practice this is actually the only case that occurs. In the above hypothesis the starting point that the density will everywhere increase owing to the extra exposure H_0 still holds. The extent to which this takes place, however, cannot be expressed off-hand by equation (1) because as a rule the sensitivity of the emulsion for the two kinds of light differs. Equal quantities of radiation of the one kind of light and of the other will not result in the same density, and even if this were so for one particular value of the quantity of radiation, it would not necessarily apply for all values. In other words, for different kinds of light the density curve might assume a different form, having a different slope in the straight part. Fortunately this proves to be not the case, for in general the slope of the density curve is to a sufficient approximation the same for all wavelengths. Further a law of addition⁴⁾ is found to apply for the photographic emulsion just as for the human eye: for a given emulsion each wavelength has a certain effect that can be expressed by a number and after multiplication by the respective number two quantities of radiation of different wavelengths can simply be added, this sum then determining the density that will be obtained by the action of the two quantities together. Thus we can simply convert the extra exposure H_0 taking place in the dark room into an equivalent exposure of the same spectral composition as that which acted upon the photographic emulsion while the photograph was being taken (e.g. daylight), or vice versa. If we now regard the symbols H_0 , H and $H_{0.3}$ used above as indications for such converted and, as regards density, equivalent quantities of radiation, the whole deduction of equation (4) remains valid.

When writing down equation (1) we have also tacitly assumed, for simplification, that the sensitivity of the emulsion is the same whether wet or dry and that the density is determined only by the quantity of radiation and not partly also by the time of the exposure (absence of the Schwarzschild effect).

In order to deduce from the foregoing the fundamental possibilities for the illumination of a dark room let us first assume that we are using a monochromatic light source. We then have to find experimentally what number of Wsec/m² of that wavelength is required to obtain a density of 0.3. This test has to be repeated with various monochromatic light sources of different wavelengths. Such measurements — in essence amounting to the determination of the spectral sensitivity curve of the emulsion in question — have been

⁴⁾ A. van Kreveld, thesis, Utrecht 1933, and *Physica* **1**, 60, 1933.

taken by Van Kreveld and Van Liempt⁵). When the values found, multiplied by a factor 0.1 according to equation (4), are plotted as function of the wavelength one obtains for each kind of film a certain curve, such as represented in *fig. 3a* for two orthochromatic emulsions and in *fig. 3b* for three panchromatic emulsions.

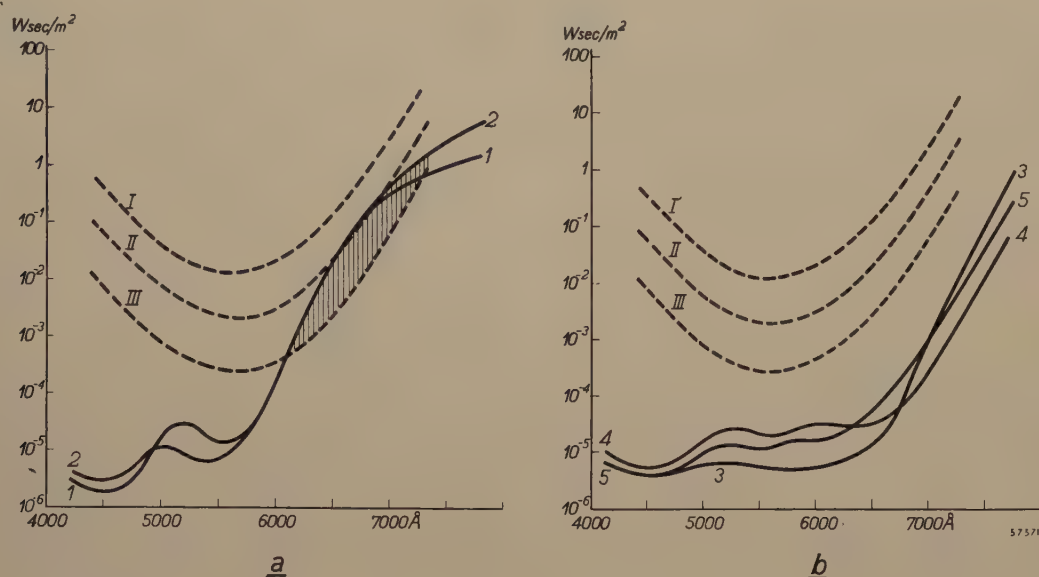


Fig. 3. One tenth part of the energy in $Wsec/m^2$ required to obtain a density 0.3 on the film, plotted as function of the wavelength,

a) for two orthochromatic emulsions: 1. Ilford Double X-Press, 2. Agfa Isochrom;

b) for three panchromatic emulsions: 3. Ilford Hyper Pan, 4. Avia Argus Pan, 5. Agfa Isopan S.S.

The dotted curves are the curves of *fig. 1*.

These curves give an upper limit for the dark-room lighting if a noticeable contrast reduction due to fogging of the negative is to be avoided. On the other hand the three curves of *fig. 1*, reproduced by dotted lines in *figs 3a* and *b*, each give a lower limit for the dark-room lighting if the density differences 1.0-1.1, 1.0-1.2 or 1.0-1.3 respectively are to be distinguishable. It is therefore only possible to solve the problem of dark-room lighting by using those wavelengths for which the corresponding dotted curve lies below the full-line curves.

Figs 3a and *b* show at once that we have already gone too far by stipulating the condition that it should be possible to observe a difference in density between 1.0 and 1.1. Neither with panchromatic nor with orthochromatic emulsions is there a wave-

length making this possible without harm to the negative. With panchromatic emulsions this is not even possible if we reduce our demands to the perception of the difference in density of 1.0 to 1.2 or 1.0 to 1.3; the corresponding curves still do not intersect each other. There is, however, an intersection of the curves in the case of orthochromatic

emulsions (see the shaded part in *fig. 3a*): it appears possible to observe a difference from 1.0 to 1.2 (illumination 0.12 lux) when using wavelengths between 6600 and 6800 Å; to perceive a difference between 1.0 and 1.3 (illumination 0.015 lux) we can use the wavelength range from about 6200 up to 7300 Å.

Dark-room safe-lights for negative emulsions

Orthochromatic emulsions

Within the shaded part of *fig. 3a* all wavelengths are not equal. The best result will apparently be obtained with a monochromatic light source having the wavelength at which the dotted curve extends farthest below the full-line curve. In practice, however, it is not possible to make a monochromatic light source for any arbitrary wavelength (only the sodium lamp can be considered as monochromatic light source suitable for common use, but its wavelength of 5890 Å falls outside the area found suitable for orthochromatic emulsions). Most dark-room lamps are therefore incandescent lamps with a bulb of coloured or

⁵) See the article quoted in footnote ³). Actually the quantities of radiation were not measured for a density 0.3 but for 0.1, since this is as a rule taken as starting point for determining the sensitivity of emulsions. For most emulsions $H_{0.3} = 2.5 H_{0.1}$ applies to a good approximation; the curves in *fig. 3* have been drawn with the aid of this equation.

lacquered glass intercepting certain parts of the continuous spectrum of the incandescent filament. For developing orthochromatic emulsions a dark red lamp is being made which gives light only with wavelengths greater than 6400 Å; see the spectral distribution given by curve *a* of fig. 4.

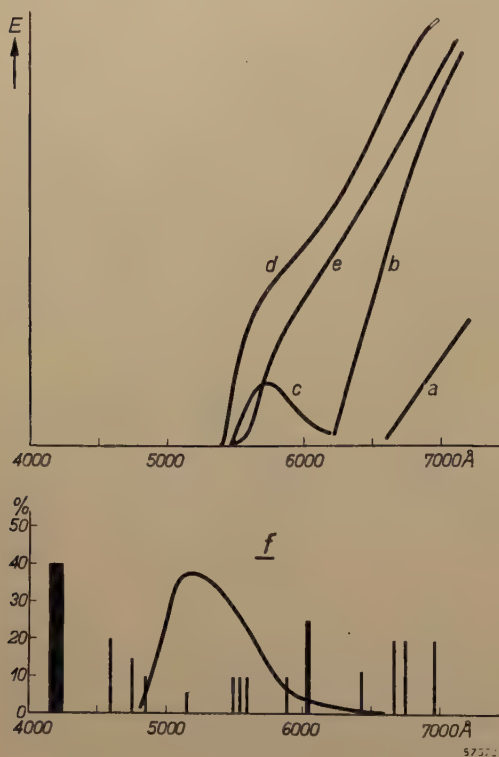


Fig. 4. Relative spectral distribution of the radiated energy of a number of dark-room safe-lights (relative measure the same for all lamps).

a) Dark red lamp for orthochromatic emulsions, flux 0.3-0.5 lumen.

b) Light red lamp for bromide papers, 1-5 lumens (also for developing X-ray photos).

c) Yellow-green lamp for bromide papers, 2-6 lumens (also for general lighting when developing X-ray photos).

d) Yellow lamp for chloride papers, 10-45 lumens.

e) Orange-yellow lamp for chloride papers containing bromide, 10-40 lumens.

In the case of the green lamp, serving for the general lighting when developing panchromatic emulsions, the radiated energy is so small that it cannot well be drawn in the same relative measure as for the other lamps. Moreover, the light from this lamp has a line spectrum and not a continuous one. In the separate diagram (*f*) the spectral position is indicated with the estimated ratio of intensity of the most important argon lines of interest to us, as also the transparency curve of the green lacquer used.

For such a more or less continuous spectrum, which in principle could be allowed to extend even farther than the intersection area of the curves in fig. 3, we have to reverse, as it were, the formulation of our problem. With the aid of the "relative sensitivity curve" of the emulsion (fig. 3) and the spectral energy distribution of the given lamp we determine the density contribution of each wavelength and by integration over the whole spectrum we can

calculate what irradiance is needed with that lamp in order to obtain in 20 seconds a density of 0.3. From equation (4) we then find the permissible irradiance (which can also be expressed in lux if desired) and with that we can find in table I by interpolation what contrasts can just be made perceptible with the spectrum in question. In the case of a wide spectrum the result will of course be the less satisfactory the more rays are emitted with wavelengths outside the intersection area. With the spectrum of the dark red lamp the illumination for an orthochromatic emulsion may amount to about 0.1 lux, with which somewhat smaller contrasts than 1.0 to 1.3 can be observed; with some routine it is thus possible to follow the developing process.

Assuming that when being examined during the developing the negative is held at a distance of about 50 cm from the lamp, it is calculated that the lamp may have a luminous intensity of about $0.1 \cdot 0.5^2 = 0.025$ candle and therefore with the normal light distribution may emit a light of a few tenths of a lumen. The dark red lamp emits this light with a filament power of 15 W. The "efficiency" is therefore very small, about 99.7% of the light being absorbed in the coloured bulb but with this low power the efficiency does not of course matter much.

Panchromatic emulsions

As regards panchromatic emulsions we have already come to the conclusion that no kind of light exists which makes it possible for a photographer to follow the developing process in the manner described above. All that can be allowed is a very weak general lighting of the dark room.

Instead of the criterion of perception of contrast which we had taken as starting point, it is now simply the perception of brightness that determines the performance of the eye. If the spectral sensitivity curves of the eye and of the panchromatic emulsion were in entire agreement — which is in fact the object of the "pan"-chromatic emulsion — then there would be no optimum spectral area to be indicated for the safe-light in the dark room. All panchromatic films, however, as is to be seen in fig. 3*b*, are still relatively sensitive in the blue, so that these rays are definitely unfavourable.

But also the red rays are not likely to be suitable. Agreement between panchromatic emulsion and the eye is desired and it is in fact approximated as far as possible for the normal levels of brightness in daylight; at low levels of brightness (illuminations from about 10 to 0.001 lux) the maximum of the relative luminosity curve is gradually shifted

towards the shorter waves, owing to the visual task of the eye being transferred from the cones to the rods in the retina (Purkinje effect). For the brightnesses that one could have in the dark room we therefore have to reckon with a reduced sensitivity of the eye for the red ⁶⁾.

It appears that for general lighting when dealing with panchromatic emulsions it is best to choose a spectral area near the maximum of the shifted relative luminosity curve, i.e. near 5050 Å. That is why for this purpose a green dark-room safe-light has been made, the maximum radiation lying around 5600 Å. The maximum cannot be brought much closer to the said optimum wavelength because the spectrum must inevitably extend towards still shorter waves and there the sensitivity of the emulsion (in comparison to that of the eye) begins to increase considerably. The flux of this lamp is much smaller than 0.1 lumen.

Formerly this lamp was made in the form of a 5 W incandescent lamp with a bulb of coloured glass ("natural glass"). Now, like the dark red and other lamps still to be mentioned, the bulb is covered with a coating of coloured lacquer. This simplifies manufacture and closer tolerances can be prescribed for the transparency. It proved to be difficult, however, to get the desired small flux for the green lamp with a filament in a lacquered bulb, since the layer of lacquer has to be so thick that it cannot safely dissipate the power it has to absorb from the filament; in course of time it would peel off. For this reason instead of the incandescent lamp a glow lamp filled with argon is now used. The argon spectrum contains lines having wavelengths favourable for the purpose; the undesired spectral lines are intercepted by the green lacquer. This can be seen in fig. 4f. The power of this lamp is about only 1 W, so that the difficulty described above does not occur. The electrodes are made in the form of two semicircular discs lying

in one plane perpendicular to the axis; see fig. 5. Thus the scanty light is emitted mainly in the axial direction of the lamp, that is to say downwards when the lamp is mounted in the normal position. In order to get some light at the side — the lamp has to serve as "beacon" for orientation of the not yet adapted eye — the bulb is frosted on the inside.

Notwithstanding the very small flux, this light has to be used with care, as will be understood from the foregoing. The panchromatic film must be exposed to it as little as possible, certainly less than 20 seconds at such a distance from the lamp that the illumination is 0.0005 lux (about 2 metres when the flux is 0.01 lumen). By way of comparison it is to be noted that the illumination of the earth on a clear starlit night with no moon averages about 0.0003 lux ⁷⁾.

The developing of positive paper

As explained in the introduction, dark-room lighting is fundamentally difficult for emulsions which while having high general sensitivity tend to approximate the relative luminosity curve of the human eye. In the case of positive papers neither one nor the other is essential. In principle the general sensitivity need not be high, since during the exposure there is no movement and the paper can therefore be exposed as long as desired. Further, the colour sensitivity can quite well be limited to a small part of the visible spectrum, say violet and blue, since the negative is in any case colourless. The general sensitivity should, it is true, not be too

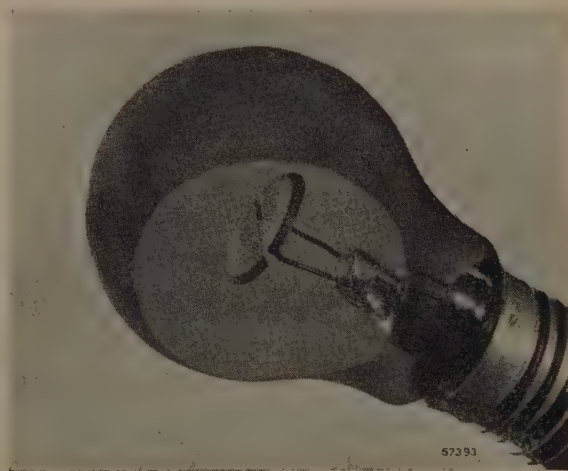


Fig. 5. Construction of the green dark-room safe-light for general lighting when developing panchromatic emulsions. It is a green-lacquered argon glow lamp with disc-shaped electrodes perpendicular to the axis of the lamp; the lacquer has been partly removed to show the electrodes. The bulb is normally frosted on the inside.

⁶⁾ It may be surprising that in the experiments regarding the perception of contrasts in the negative a sensitivity curve was found corresponding approximately to the relative luminosity curve of the eye at high levels of brightness (fig. 1), although the level of illumination in those experiments was already in the Purkinje range. A possible explanation for this is that when one is looking sharply at an object it is particularly the central part of the retina (the fovea), where there are almost exclusively cones, that is brought into action. The sensitivity of the eye does not then depend upon the level of brightness. H. Arens and J. Eggert (Z. wiss. Phot. 24, 229-248, 1926) have made a study of the consequences of the Purkinje effect for dark-room illumination, but without differentiating between the criteria for the general lighting and those for the examination of the negative. A separation of the lighting for these two objects, making allowance for the Purkinje effect, has been proposed specially for the developing of X-ray films by F. Luft and M. Biltz, Trans. Ill. Eng. Soc. Japan 25, 101-112, 1941.

⁷⁾ P. J. Bouma, Philips Techn. Rev. 5, 297, 1940.

low, so that reasonable times of exposure can be allowed for when making enlargements. Nevertheless, it is much easier to provide a useful lighting of the dark room here than is the case for the developing of negatives.

Bromide papers

The matter is relatively most difficult with the sensitive bromide papers, the relative sensitive curve of which extends from the violet to the yellow and orange. The best light to be used in the dark room is that with wavelengths above about 6200 Å, like that for orthochromatic negative emulsions, only with a much greater luminous intensity. The bulb of the light red lamp made for these papers is coated with a lacquer similar to that used for the ruby lamp but with a greater transparency. The spectral distribution of this lamp is given in fig. 4b in the same relative measure as the other curves. The flux is 1 to 5 lumens, thus ten times as high as that of the dark red lamp.

When developing positives under this light a remarkable difficulty may arise. When looking at a positive under red light in the dark room we have the impression that contrasts in the picture are much more pronounced than they appear in white light (given the same or greater illumination). Consequently, when we see the picture in daylight the contrasts are disappointing and the positive is judged to be too flat. This phenomenon, which also occurs in road lighting with sodium lamps⁸⁾, is related to the already mentioned Purkinje effect and can be explained as follows. When a small surface is illuminated with a few lux of a long wave kind of light then with diminishing reflection coefficient the "subjective" brightness drops more than proportionately, owing to the fact that with diminishing brightness the maximum of the relative luminosity curve of the eye is shifted towards the short waves (in other words the eye becomes less sensitive for long waves). When we plot as function of the wavelength of the light the relation between the "subjective" contrast and the contrast by daylight for two areas the reflection coefficients of which are in the ratio of 1:10, graphs are obtained as shown in fig. 6. Each curve represents this relation for a certain brightness of the darker area. The phenomenon of contrast magni-

fication owing to the Purkinje effect appears to be strongest when this brightness amounts to about 0.01 c/m² and it is still perceptible at 0.3 c/m², e.g. the range of brightnesses to be considered for developing bromide papers⁹⁾.

An experienced photographer will of course know how to allow for this effect by developing somewhat longer. It can, however, be entirely avoided by not using red light in the dark room. Also with yellow or yellowish-green light a useful illumination is permissible for many kinds of bromide paper, though somewhat less than in the case of red light. Fig. 6 shows that the disturbing effect hardly occurs at all when using a light with wavelengths between 5200 and 5500 Å. At 5200 Å, however, there is a rather great risk of fogging the paper. A lamp has therefore been designed with a maximum in the spectral distribution at about 5700 Å, whilst the spectrum extends on the short-wave side to 5400 Å and on the long-wave side

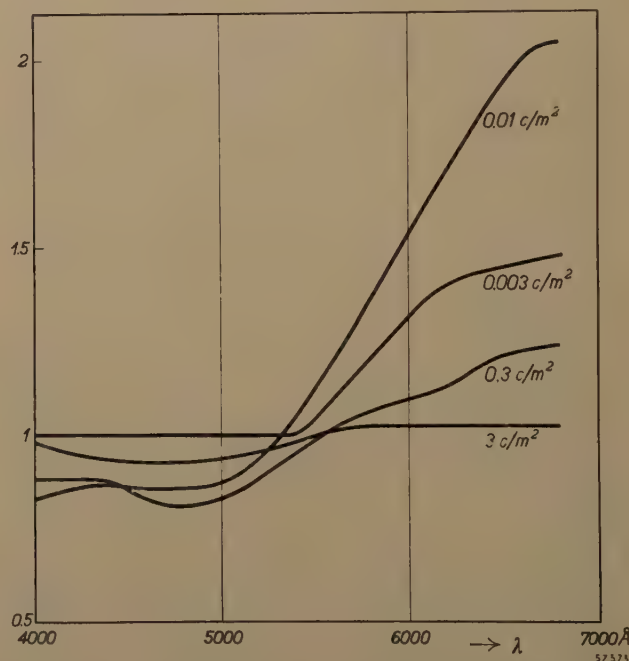


Fig. 6. Relation between a contrast observed under light with wavelength λ and the contrast observed under light of the composition of daylight, as function of λ . Two areas were observed the reflection coefficients of which bear the ratio of 1:10. Each curve applies for a different level of illumination; the brightness of the darker of the two areas is used as parameter. (Taken from the article by Van Liempt quoted in footnote⁸⁾).

⁹⁾ Even without differences in colour, when examining a positive in the dark room and in daylight there would be a difference in the judgement of the contrasts owing to the difference in the level of illumination. This effect, however, is of less consequence. When developing negatives one is not concerned with the problem as a whole, partly because it is not the judgement of the magnitude of the contrasts but only their appearance that serves as criterion, and also partly because this work has to be done with still lower levels of illumination where the effect is again less felt (see fig. 6).

⁸⁾ P. J. Bouma, Philips Techn. Rev. 1, 166, 1936. — For dark-room illumination the effect has been further investigated by J. A. M. van Liempt, Zur Physik des Dunkelkammerlichts für Schwarz-weiß-Positive. Physica 10, 645-660, 1943, where a closer definition is given of the conception "relation between contrast perceptions" used in this article.

there is an unavoidable gradual drop to about 6500 Å; see fig. 4 curve *c*. The flux of this yellow-green dark-room lamp, having a power of 15 W, amounts to 2.6 lumens.

This yellow-green lamp proves to be very useful also for the general lighting of dark rooms for X-ray films; close to a developing bath, however, the light red lamp has to be used (see footnote ⁶).

Chloride papers

In the case of chloride papers the spectral sensitivity curve extends from the violet no farther than about 5000 Å. Since in this spectral range the incandescent lamp gives little radiation, when making enlargements with incandescent lamps very long exposure is required, the more so since in enlargement apparatus only lamps of a limited power can be used in view of the heat developed. Owing to their greater sensitivity range bromide papers are more satisfactory in this respect and are therefore preferred by photographers although the chloride papers as a rule give more contrast. Nowadays, however, in the high-pressure mercury lamp (e.g. the HP 80 W) we have a light source yielding a relatively large amount of radiation just in the spectral range in which the chloride paper is sensitive. By using a mercury lamp in the enlargement apparatus it is therefore possible to make enlargements very quickly also on chloride paper and, owing to the limited spectral sensitivity range of chloride paper, it is then possible to provide ample illumination in the dark room¹⁰). For the latter purpose one can use for instance an incandescent lamp with a yellow bulb which emits only light in the wavelengths above 5000 Å and, in the case of a 15 W lamp, yields a flux of 10.45 lumens (for the spectral distribution see curve *d* in fig. 4). Still better, however, is the sodium lamp. The sensitivity of the chloride paper, provided it really contains no bromide, is so small at the wavelength of the yellow sodium light that one can safely use a 45 W sodium lamp, yielding 2700 lumens. In that case the dark room no longer does honour to its name, for it is then much more brightly illuminated than most living rooms.

In the spectrum of the sodium lamps some green and bluish-green lines occur (originating from the sodium and from the neon always present in the sodium lamp) for which the chloride paper is sensitive. In order to intercept this radiation the sodium lamp can be fitted with an orange-coloured

vacuum jacket instead of the normal plain vacuum jacket.

For chloride papers containing bromide an incandescent lamp is being made coated with a lacquer the colour of which is between yellow and light red. The spectral distribution of this orange-yellow lamp (see curve *e* in fig. 4) lies as far as possible towards the short-wave side so as to avoid trouble from the above-mentioned effect of increased contrast perception.

Although, as we have seen from the foregoing, entirely different kinds of light are required for the various jobs that have to be done in the dark room, if necessary it is possible to manage with one single incandescent lamp by placing in front of it a filter of a certain colour according to the work in hand. This is a method frequently applied but it does not constitute any fundamental simplification for the photographer. In particular it lacks the advantage of being able to switch over easily from one kind of light to another when a number of different lamps are installed. This may be of importance for instance when it is desired to combine a very weak general lighting with a stronger and possibly differently coloured light to be switched on momentarily for the examination of a negative or a positive.

As regards the general lighting it may be added that if desired this can be indirect, one or more lamps of the type indicated being directed towards the ceiling of the dark room, given a light colour for that purpose. In the case of positive papers, where the picture is viewed in incident light, such a diffuse lighting (of a suitable level) can quite well be used also for checking the process of development itself. We shall not go further into the advantages and disadvantages of various lighting systems here.

Compiled by G. D. RIECK.

Summary. The fundamental possibilities for the lighting of a dark room while developing photographic negatives have been investigated by Van Kreveld and Van Liempt. The results lead to the determination of the most favourable spectral ranges for the light emitted by dark-room safe-lights. In the case of panchromatic emulsions it appears that only an extremely weak general lighting, preferably of a green colour, can be allowed; in the case of orthochromatic emulsions, by limiting the spectrum of the safe-lights to wavelengths above about 6400 Å the illumination can be increased to about 0.1 lux, under which light it is indeed possible to follow the developing process. For positive papers the problem of dark-room lighting is fundamentally simpler. Some dark-room lamps are mentioned which are suitable for bromide and for chloride papers respectively. The most favourable is the combination of chloride paper and a high-pressure mercury lamp in the enlargement apparatus and a sodium lamp as dark-room lamp. A sea of light is then available in the "dark-room".

¹⁰) See Philips Techn. Rev. 3, 91, 1938.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk can be obtained free of charge from the address printed on the back cover.

- 1816:** W. G. Perdok and H. van Suchtelen:
A sensitive apparatus for qualitative testing of crystals on piezo-electricity (Appl. sci. Res. 's-Gravenhage **B1**, 195-204, 1948, No. 3).

A modern apparatus for qualitative testing of crystals on piezo-electricity, based on a principle announced by Giebe and Scheibe, is described. It is easily built and functions very constantly and reliably.

- 1817:** J. Volger: On estimation of tenths (Appl. sci. Res. 's-Gravenhage **A1**, 215-218, 1948, No. 3).

A test is described which was made to check the possibility of estimating to one-tenth of a scale unit the position of a pointer on the scale of an instrument. It is proved that systematic errors arise in this sense that a general and outspoken tendency exists to read 0.3 and 0.4 one-tenth too low and 0.6 and 0.7 one-tenth too high.

- 1818:** H. C. Hamaker: De invoering van moderne statistische methoden en opvattingen in het massa-producerend bedrijf (T. Efficiëntie en Documentatie **18**, 266-269, 1948, No. 11). (The introduction of modern statistical methods and ideas in mass-production; in Dutch.)

General considerations on decisions to be taken on the basis of essentially inaccurate data and on the use of sampling.

- 1819:** H. C. Hamaker, J. J. Taudin Chabot and F. G. Willemze: De tolerantiekeurigen van gehele partijen (T. Efficiëntie en Documentatie **18**, 235-241, 1948, No. 11.) (Tolerance testing of whole lots; in Dutch.)

General considerations on inspection by sampling. Simple and double sampling. Description of a sampling table in use in the Philips Works (Netherlands).

- 1820:** H. C. Hamaker: Foutentheorie en wiskundige statistiek (Statistica **2**, 177-205, 1948, No. 5/6). (Theory of errors and mathematical statistics; in Dutch.)

The writer advocates the use of standard deviation as a means of indicating the inaccuracy of observations. The mean and the standard deviations are subject to simple mathematical relations, independent of the form of the frequency curve. These relations are discussed and employed for a thorough treatment of the degree of rounding off permissible in practice. The maximum possible rounding interval is either $1/2$ of the standard deviation or $1/6$ of the range computed from 5 to 10 observations or $1/6$ of the maximum mutual difference observed in ten pairs of observations. The rounding interval should at least be $1/5$ of the maximum just specified.

- 1821:** F. A. Kröger: The incorporation of uranium in calcium fluoride (Physica **14**, 488, 1948, No. 7).

Strongly fluorescent $\text{CaF}_2\text{-U}$ is known to be obtained when CaF_2 with 0.004-0.5 mol % UO_3 is heated together with 6-25 mol % CaO ; if no CaO is added the fluorescence is considerably weaker. The writer supposes that uranium is incorporated in such a way that the excess of charge of U ($6+$) over Ca ($2+$) is compensated by a simultaneous replacement of four F^- -ions by four O^{2-} -ions. The result, therefore, can be described as a solid solution of Ca_2F_4 with $(\text{CaU})\text{O}_4$. The centre of fluorescence is a uranium ion, surrounded by four O^{2-} -ions and four F^- -ions.

- 1822:** F. A. Kröger and W. Hoogenstraaten: Decay and quenching of fluorescence in willemite (Physica **14**, 425-441, 1948, No. 7).

With the aid of measurements of the efficiency and the decay of the fluorescence of willemite, it is shown that fluorescence excited by short-wave ultra-violet radiation is quenched by two kinds of radiation-less processes. One starts from the high excited state reached in the excitation process; its rate is governed by a linear process which, competing with the quadratic process leading to fluorescence, causes the efficiency of fluorescence to be dependent on the exciting intensity. This process is increased by iron and also by ball-milling. The other radiation-less process starts from an excited state of the manganese centre. It runs parallel to the slow fluorescence transition and thus influences the decay of the fluorescence. It increases strongly

with temperature; the variation can be satisfactorily described with the aid of an activation energy. For excitation by long-wave ultra-violet only the latter process plays a part.

- 1823:** Balth. van der Pol and H. Bremmer: Modern operational calculus based on the two-sided Laplace integral (Proc. Kon. Ned. Akad. Wetensch. Amsterdam **51**, 1005-1012 and 1125-1136, 1948, No. 8 and 9).

After having made some general remarks on Laplace transformations the writers claim the superiority of the two-sided form (integration from $-\infty$ to $+\infty$) over the one-sided form (integration from 0 to ∞). This is illustrated by examples: δ -function, linear differential equations with constant and with variable coefficients, originals having arguments of exponential character, operational identities, generating functions.

- 1824:** C. J. Bouwkamp: On the mutual inductance of two parallel coaxial circles of circular cross-section (Proc. Kon. Ned. Akad. Wetensch. **51**, 1280-1290, 1948, No. 10).

Calculation of the mutual inductance of two parallel circular loops of circular cross-section (coaxial toroids). A series development is given. The coefficients are expressible in terms of a simple integral involving Bessel functions, which can be readily evaluated at least for the lower order terms. Finally approximate expressions for the mutual inductance are given.

- 1825:** Joh. Hoekstra and H. A. W. Nijveld: The determination of the hardness of organic films (Rec. Trav. chim. Pays-Bas **67**, 685-689, 1948, No. 11).

An apparatus is described for the determination of the indentation hardness of organic films. The deepness of the indentation can be measured with an accuracy of 0.1μ . The measurement is performed during the application of the force.

A few results are given, indicating how the hardness of some lacquer films changes with time and thickness of the layer.

- 1826:** N. W. H. Addink: A general method for quantitative spectrochemical analysis (Rec. Trav. chim. Pays-Bas **67**, 690-696, 1948, No. 11).

Up till now Gerlach's internal standard method has been applied to all kinds of quantitative spectrochemical analysis. According to this method it is necessary to prepare for each individual material to be analysed a series of samples in order to

set up working curves relating concentration and intensity ratio of lines of the element sought for and the standard element. Harvey (1947) uses the background near a line of the element as a kind of internal standard and his book contains many useful data for two-component systems. However, materials containing many major constituents such as mixtures of salts, oxides or metals cannot be analysed with great accuracy according to Harvey's method. In the following paper a general method derived from Harvey's is described; it can be divided into two parts, one for the rough estimation of the element concentration and a second part for the exact determination, obtained by successive additions of the element sought for. If the straight portion of the characteristic curve of the photographic emulsion is used a simple evaluation of the concentration is given, whereas the knowledge of the accurate shape of the characteristic curve is not essential.

- 1827:** F. de Boer: On the use of Evjen's method in calculating Madelung potentials (Rec. Trav. chim. Pays-Bas **67**, 697-702, 1948, No. 11).

Evjen noticed that, in evaluating the sum $\sum e/r$, a reasonable accuracy may be obtained by summing up the contributions of the ions of a finite part of the lattice if this part is, as a whole, electrically neutral. The complications arising if this condition is not fulfilled are investigated for a simple lattice (CsCl, bounded by cubic faces). A correction is calculated and applied to the spinel lattice.

- 1828:** A. Claassen and W. Westerveld: The photometric determination of cobalt with nitroso-R-salt (Rec. Trav. chim. Pays-bas **67**, 720-724, 1948, No. 11).

As the result of a discussion on the choice of the most suitable wavelength to be used in the photometric determination of cobalt with nitroso-R-salt, a wavelength of $550 m\mu$ is recommended, using absorption cells of 2 to 5 cm length.

The interference by copper and nickel is extensively dealt with. Some data are given on the interference by other elements.

- 1829*:** J. H. van Santen and J. Th. J. Overbeek: Discrete energieniveaux in ionen-roosters (Chem. Weekbl. **44**, 285-291, 1948, No. 21). (Discrete energy levels in ionic lattices; in Dutch.)

If ions of both signs unite to form a crystal lattice the discrete energy levels are generally broadened to energy bands. Transitions between such levels

manifest themselves as rather broad emission or absorption bands. There are, however, some cases in which the interaction between ions of one kind and between these ions and neighbouring ions of another kind is so slight that the energy levels and the transitions remain sharp. This will occur especially if the radiation takes place in electron shells far from the periphery. A survey of several cases is given, showing how the energy levels of the free ions are influenced by the electric crystal fields. Especially rare earth ions and those of the iron group are dealt with. Finally the influence of extremely strong crystal fields is briefly discussed.

1830: J. A. Haringx: Het onderzoek van staalplaat met behulp van gekerfde proefstaven (De "Ingenieur" 60, Mk 141-Mk 148, 1948, No. 51). (The examination of mild steel plate by means of notched test specimens; in Dutch.)

The examination of mild steel plates by means of notched test specimens aims at the determination of their disposition to brittle fractures. Although something is known about the factors giving rise to such brittle fractures, it is shown that for the time being we are not able to fix special specifications for the steels on account of theoretical considerations. One must therefore rely upon the results of more or less orientating tests. Some of these will mutually be compared in a research programme arranged by the Welding Society in the Netherlands in cooperation with the Belgian "Commission Mixte des Aciers", and are briefly described here. Further a review is given of the interesting investigations recently published by Mrs. Tipper and by Bagsar. The endeavour by Mc Gregor and Grossman to correlate a given stress distribution with the profile of the notch in the test specimen is also discussed.

1831: J. F. H. Custers: A new method for the determination of preferred orientations (Physica 14, 453-460, 1948, No. 7).

A new method is indicated for the determination of preferred orientations of flat specimens. It is shown that this method implies a somewhat easier construction of pole figures. Moreover it will

simplify appreciably the calculation of the absorption in the specimen in its different positions during the taking of a series of X-ray pictures.

R 94: J. A. Haringx: On highly compressible helical springs and rubber rods, and their application for vibration-free mountings, I (Philips Res. Rep. 3, 401-449, 1948, No. 6).

A survey of the contents of a series of six papers, of which this is the first, is given in the introduction. The remainder of the first paper is devoted to a study of the elastic stability of helical springs under compression or under combined compression and twist. It is shown that, if the problem is simplified by replacing the helical spring by an elastic prismatic rod, for every point of the central line its rigidity with respect to shearing must be referred to the transverse force acting in that plane through the point considered, which in the unloaded state is normal to the central line of the rod but is no longer so in the deflected state. From this interpretation of the simplified model a new relation is deduced between the relative compression at which buckling occurs and the ratio of the length to the diameter of the spring. For this ratio there exists a limiting value below which no buckling occurs, not even under complete compression, and which is dependent only on the method of fixing the spring ends. A more accurate calculation, which takes the helical structure of the spring into account, confirms that the wire diameter and the number of coils are of secondary importance provided the pitch of the helix is less than, say, half its diameter.

R 95: W. Elenbaas: Dissipation of heat by free convection, II (Philips Res. Rep. 3, 450-465, 1948, No. 6).

Continuation of R 90. For the contents of this article see these abstracts No. 1773*.

R 96: C. Zwikker: Anticaustics - A cord construction and a general formula (Philips Res. Rep. 3, 466-473, 1948, No. 6).

The author describes a method for constructing anticaustics — if the caustic is given — by generalizing the well-known cord construction for the ellipse. An analytical method of calculation of the anticaustics is developed by means of the geometry of the complex plane.